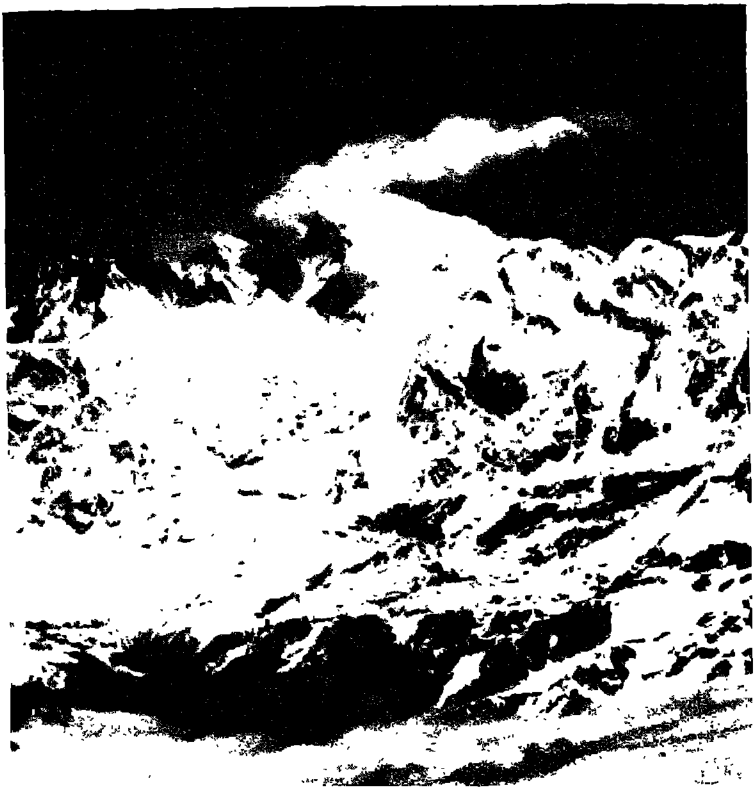
DUST



[By courtesy of Houston-Mount Everest Flight.

FIG. 1.—THE EARTH'S HIGHEST DUST-CLOUD.

The ice plume—several miles long—blowing off summit of Everest. At a height of over 29,000 feet, it is about 13¾ miles above the earth's possible lowest dust deposit. P. Bartsch of Smithsonian Institute having established a new ocean depth record at 44,000 feet, for Nares Deep.

[*Frontispiece.*

D U S T

by

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"This desert soil
Wants not her hidden lustre, gems and gold."

MILTON.

"Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great Part of the Phenomena of Nature?"

NEWTON.

PREFACE

It seems that the boundary between the co-essential principles of scientific imagery, and strict, cold, factual rectitude ought to be elastic and variant so as to meet the need of any particular subject. The necessities of such a subject as dust may imply some stretching of this boundary in the appropriate direction. Keeping in view these requirements, the underlying aim of this monograph has been to reach and maintain full scientific poise.

Though exhaustive treatment of such a subject as dust might be regarded as only possible within the confines of a special encyclopædia, that, however desirable, would not present the subject as the living, coherent system which it actually is. In the present state of knowledge the immediate necessity seems to be the outlining, or skeletal presentation, of this system to the extent of available knowledge, even though achieved at the expense of completely exhaustive treatment. For exhaustive treatment will require the inclusion of data at present unascertained—perhaps unsuspected—necessitating a long attendance, during which such material as is available would remain, unfortunately, unco-ordinated.

This desirable co-ordination, presenting together with little-known aspects of dust, serious, widespread, implications of current and increasing importance, is the purpose of this monograph. Offered to all interested, there is undoubtedly an existing need for a study of dust as regards its nature, varieties, determination and effects—for dust concerns each individual at some point.

Acknowledgment is gratefully made to all authors, other workers, and institutions, references to, or quotations from, whose publications—in the spirit of scientific comparison and advance—have been made. Likewise to those whose courtesy has allowed reproduction of illustrations. Also to various libraries—in particular the Technical Reference Department of Sheffield Public Library—for spontaneous and willing assistance, freely given.

S. C. Blacktin.

June, 1934.

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SECTION ONE

DUST CONSIDERED GENERICALLY

CHAPTER I

INTRODUCTION

The Relative Obscurity of Dust Studies.

Dust is one of the most immense and widespread commonplaces. Neither exclusively empirical, nor exclusively regulated in Science or Art, dust belongs to all these spheres. It plays a part, an immense and important one, in all aspects of life on the earth—human or otherwise. Its conception is a universal conception.

It has another important aspect. It is generally unpleasant, undesired. Dust in the eyes, mouth, lungs, effects, or imagination of human beings, is generally anathema.

Either of these aspects taken alone might have heretofore educed the thorough study which so immense a subject merits. Taken together—chiefly due to the psychological effect which causes the human mind to repress what it dislikes—they have resulted in this huge, important subject being relatively neglected.

In essentials, time makes very little change in mankind. Dust, undoubtedly is, and always has been big enough to class amongst the essentials. To the ancient Egyptian crossing the wind-blown desert, dust in the eyes would force his mental repression of the subject in as much annoyance as it would that of the pedestrian in the dirty quarters of our modern cities, and the only difference in expression of feeling after an interval of 6,000 years, would be one of language.

But in these days, in the inductive philosophic spirit of inquiry brought powerfully into focus by Roger, and then Francis Bacon, all is examined. Dust studies will repay the application of this spirit equally with any other subject. This may be termed a pioneering subject, but when it is generally realised that the importance of dust for all earthly life, is similar to that of the air breathed, its study will be intensified. All life is continuously surrounded-by and enveloped-in dust.

DUST EMPIRICALLY DEFINED.

Dust may be empirically defined as a powdered or finely-divided form of homogeneous or heterogeneous solid substances, mixed with or without any due regard to, or any immediate knowledge of, particle-size difference or limits, proportionality, or condition, amongst its parts.

It may be regarded as an immense terrestrial nebula. The essential empirical characteristic of dusts is their elusiveness. Though so widely distributed and so immense in amount it is relatively the merest suspicion that is ever seen. This also is generally because it is undesirable—causing annoyance. Allied to the natural objection, this elusiveness has discouraged classification.

PRODUCTION OF DUST.

All materials in greater or lesser degree, are more or less liable to form dusts. Except when the result of growth or manufacture—even sometimes then—dust is degraded organised material. This accounts for its heterogeneity. Degradation can be due to numerous processes whether (*a*) in nature, or (*b*) due to man. Thus (*a*) weathering, erosion, volcanic action, mutual attrition, wind action on plants and trees, rainfall, etc., are added to (*b*) mechanical action, habitual human movements, chemical actions, industrial operations. The immediate result has been a widespread accumulation in all parts of the earth, at all times, of a heterogeneous mixture of dusts degraded from all shapes and forms of created or artificial objects. This follows at once from the law of indestructibility of matter.

In one sense—and a very real sense—the earth is one huge dust heap.

It is obviously not possible to determine exactly the proportions in which the elements exist in the world's dusts. Much less to know the dimensions of each of the constituent particles and their proportions. The working jeweller periodically takes up the floor of his workshop; has the wood burned at a refinery; and the trodden-in metal dust or particles extracted. He saves the "handwashings" from his working hours, for the same purpose; his waistcoat periodically suffers the same process as the workshop floor. In such cases the precious dust content is known to be there, and is recovered. Who shall

say where the dust whose gradual formation over the years, as the gold watch-chain or finger-ring gets thinner and thinner, is to be eventually found ?

It is largely the lack of classification of dusts which is responsible for the way they have been ignored ; treat as negative rather than positive ; allotted to the limbo of chaos, rather than the order of reality.

Classification.

Though Aristotle seems to have had some notion of introducing dusts into the scheme of things, classification seems never to have been seriously accomplished.

Whilst scientific induction is now applied in all directions, it should not be overlooked that the very methodical nature of the scientic outlook will insist on the primary consideration of those subjects which are the more amenable to its discipline. On this account where, at first sight, some reason for a serious classification of dusts might seem to make itself evident, e.g. its most ancient lineage, it will be eventually realised that, actually, the study of dusts is likely to be relegated to a tardy attention.

Widespread Nature of Dusts.

Very few people have actually seen in other countries or spheres the conditions with which they have gradually become familiar in their own. But with the assistance of common sense and his knowledge of geography, every man realises that just as a rising wind raises a dust cloud in his immediate neighbourhood, so it will in, say, central Asia. And within differences of degree, internal and external objects and decorations will similarly become covered with dust films in both places. So that the general conclusion is reached that dust is liable to be blown about wherever on the globe the wind is sufficiently raised, hence, that dust is lying over all the earth's surface. And even the intensely frozen regions project no exception. There are supporting conclusions which can be co-ordinated with more definite and obvious natural phenomena. Thus particular places in various parts of the earth have immense, exclusive dust collections. The general knowledge of the existence of these dunes and deserts implies positively the widespread nature of dusts.

Experiment and research—non-geographical—have also emphasised the wide distribution most emphatically, as, for instance, the dust-counting work of J. Aitken (28), and the study of snow-dust clouds on mountains by A. Stager (134). Wherever vehicles are propelled, or the foot of man treads, dust clouds are seen to be raised, and the manufacturing of numerous articles, from the stone-grinding of cereals for food in the east, to the manufacture of silica bricks in the west, gives rise to dusts in greater or lesser degree.

Temporary natural phenomena such as sand-storms—a prevalent feature in widely separated neighbourhoods—and volcanic dust, known to permeate the upper atmosphere thousands of miles from its place of origin producing specially-fine sky effects, bear witness.

Remembering the ever-active phenomena of weathering, and the immense general amounts of suspended and settled dusts produced thereby, hardly more evidence of the spread of dusts is needed. These phenomena imply extension in time as well as in space.

In Book II of the "Iliad," Homer (109) sings:

> The gathering murmur spreads, their trampling feet
> Beat the loose sands, and thicken to the fleet;
> With long-resounding cries they urge the train
> To fit the ships, and launch into the main,
> They toil, they sweat, thick clouds of dust arise
> The doubling clamours echo to the skies.

and again:

> In just array draw forth the embattled train
> Lead all thy Grecians to the dusty plain.

These are two occasions of many when Homer refers to the dustiness of the land or to dust clouds raised by the tramp of armies. Such evidence of the world's greatest poet, an astute eye-witness of those ancient times confirms the conclusion implicit in erosion and common sense.

Like men, dusts have varying dates or periods of birth allied to a habitation effect or environment. It is less certain that they will have periods of decay and death, though they will tend to spread from locality to locality. The dusts of eldest lineage will be those produced in nature, e.g. prehistoric volcanic and desert dusts; less old, i.e. historic, ancient and

mediæval dusts such as would be produced by man in the war-like and domestic ages—many of which might previously have belonged to the continuously augmented prehistoric dusts. The newest dusts will be those of the machine age, produced say, during the last 200 years—very numerous, continually augmented, with a subsidiary time-order of their own.

Obviously—excepting volcanic dusts—the prehistoric and less-old dusts, will be superficial earth dusts, whilst the newest dusts will be internal earth dusts, i.e. from materials taken out of the earth rather than from its surface. This is a very significant distinction exemplified by, say, ash dust from primitive fuel (wood), and ash dust from modern fuel (coal).

The new knowledge of the physics and chemistry of surfaces has greatly extended the class of desirable dusts. This manufacture of dusts for their own sake, will probably be yet considerably further extended, and the transition point is probably now arriving from the idea of dust chiefly as a nuisance to dust chiefly as an utility.

The most ancient dusts would be more generally distributed due to maximum constraint of natural distributing agents; middle-age dusts would be mostly concentrated in mediterranean and eastern regions; whilst modern dusts will be preponderatingly found in western regions. The distinction will suffer general checks such as movement by wind systems, and blurred already, will become more so in process of time—with the exception of utility dusts manufactured, stored, and used for definite purposes.

The steady removal of dust over the earth's surface by the world-wind systems is so immense as to be unamenable to the comprehensive visual study of man. But restricted natural parallels exist. In South Africa dust storms are one of the most outstanding features of its characteristic climate, and the literature of desert and mediterranean travel is littered with accounts of the danger and discomfort of sandstorms experienced by numerous travellers. Above mountain snow-lines the world over, blown snow dust is a prevalent feature. In fact, the incidence of dust is so wide, that the real problem is the study of the relative densities of dust systems in various geographical situations and mere localities, and their relative constitutions—content, conditions and particle-size—rather than that of isolated dust systems in an otherwise clear atmosphere over an otherwise clean-surfaced earth. In the broadest sense,

however, rate of dust formation seems to have varied from age to age. Thus, after a glacial epoch, more rapid degradation occurs owing to the loose matter left by the glacial grinding action.

Dust is the end-product of most material, solid, degradations, a point being increasingly reached, despite varying intermediate stages due to varying materials. Unless, therefore, some vast, natural, operation counteracts, building up fresh solids from dust, the dust load (wet or dry) and atmosphere of the earth is an increasing accumulation. Such building-up though actually, in one sense, having been an occurring progression in the production of all sedimentary (secondary) rocks, is quite foreign to what would be the truly reversible, thermodynamic process of the reorganisation of similar original object forms. For it is a building-up into totally different forms, of the fine particles formed, cemented together under pressure. The units are still the degraded particles, and as in the case of crystals, there seems to be a natural obstacle to growth of particles in dust systems above a certain size. This emphasises the true particle trend in dust systems as being disintegrational, rather than aggregational.

Dust, therefore, seems universally to exhibit an entropy of solid matter.

Rain plays an immense part in removing degraded solid matter, each drop more generally requiring a particle nucleus. Thus, A. Geikie (138) states: "Day by day the process is advancing. So far as we can tell it has never ceased since the first shower of rain fell upon the earth."

CHAPTER II

DUST IN GENERAL

THE STAUBOSPHERE.

COEXISTENT and probably co-extensive with the earth's atmosphere—in it, but not of it—is an immense continuous (as regards existence) solid particle system. This system of the same order of importance as the atmosphere in the maintenance of life on the globe, merits, at the very least, a definite individual title.

The title STAUBOSPHERE is suggested (*a*) because it is fully descriptive; (*b*) it is a complex of those two languages which have been the medium of most modern scientific advances; (*c*) it suggests the necessary relationship with the atmosphere, and is a title readily adaptable by the wider public; and (*d*) it is euphonius.

Evidence for the coexistence of the staubosphere with the atmosphere is strong as shown at many points in this monograph, and whilst this has been recognised, such recognition quite tacit, seems now to merit specificness. The coexistence is, of course, one of extension in time and space, not in variation of quality or quantity.

The impression grows of the present obscure and will o' the wisp immensity and profundity, of the subject, with examination. Its great importance grows obvious, set against a hazy background of largely haphazard and unorganised knowledge.

Difficulties are multiplied when a huge, unnamed system is discussed. In sciences of "should" laws, e.g. economics, the difficulty of nomination is an ever-abiding one, and easily gives rise to confusion. But in sciences of "must" laws, e.g. jurisprudence, and of "will" laws, e.g. physical sciences, classification is so ordered that only when the scientific boundaries are being advanced may the difficulty of nomenclature arise. It arises in finding a title for this vast realm, now known—so little as known at all—as Dust.

The title STAUBOSPHERE, is therefore, now projected, as more elegant and convenient in constant repetition than "the dust contained in the atmosphere"—clumsy, though otherwise necessary, phraseology.

DUST SIGNIFICANCE IN LIFE AND NATURE.

There can be no doubt of the existence of prehistoric dusts, tacitly recognized in one hypothesis of the origin of life on the earth, viz. that life was first conveyed to this planet with cosmic dust as the carrier—J. A. Thompson (111). Though no man might be present to observe the darkening of the sky, or the subsequent enhanced beauty of the sunsets, volcanic action of the Peléean type—to say the least—has doubtless prehistorically produced dusts. Again, in the biblical account of the creation, man was formed "from the dust of the earth."

Whether, therefore, the evolutionary, geological, or orthodox account of the inception of life on the earth be considered, the so-long-neglected dust, seems to have been one of the chief agents present thereat.

Under the ancient influences of wind and rain, small fragments would fall from rocks, gradually disintegrate, and their disintegrated particles would be swept-up by winds to form small, or large, dust clouds. The winds would now be charged with an abrasive medium, instinct with the capacity to form more dusts. Thus A. W. Grabau (112) states: "It is not merely that the wind blows away what had already been loosened and pulverized. The grains of dust and sand are themselves employed to rub down the surfaces over which they are driven. The nature and potency of the erosion done by sand grains in rapid motion is well illustrated by the artificial sand blast. The same process is sometimes seen at work in nature. Thus a large sheet of plate glass once a window in the lighthouse in Cape Cod was so worn by the impact of sand grains driven against it by the wind during a storm of not more than 48 hours duration that it was no longer transparent. In some places it has been noticed that the stones exposed to the sand drift are worn into facettes, and have sharp edges."

But perhaps better evidence than geological of the prehistoric and original existence of dusts, is the necessity of dust particles for the formation of much rainfall (hygroscopic nuclei being included as dust particles). Unless, as seems

quite inconceivable, there were no sun, no sea, no rivers, and no rain; and unless—admitting the existence of these essentials—" Rain " fell on the earth in huge sheets of liquid, an atmosphere well-charged with dusts was approaching a necessity. For, though as C. T. R. Wilson (1) and Lenard (2) have shown, condensation may occur on ions, very high supersaturation is required.

In addition to its supposed necessity for the first institution of life on the earth, dust therefore was one of the first necessities in the prime natural cycle: sea, sun's heat, evaporation, rainfall, river-flow, sea. And since, without the operation of this cycle, Man as known, could not long have continued on the earth, the existence of the human race; modern civilization; and all consequent human pursuits; have been largely made possible by the prehistoric existence of dust.

It is, of course, not possible to say to what relative extent the prehistoric atmosphere was dust-charged as compared with modern atmosphere. Owing to degradation through the long ages, it is almost certain that, despite counteractions, the present dust content of the air is much more formidable than the prehistoric one. At any rate, in variety, though large changes would be doubtless introduced by geological epochs such as ice ages and pluvial periods. If so, and incidentally, this might affect the longevity of individual man as between the two periods. It is, however, easy to conceive a possible state of affairs wherein the general staubosphere was no greater than that obtaining now over, say, mid-Pacific, out-of-all-proportion less than the dust content of the air over cities and towns. Nor can there be much more certainty as regards the quality of the prehistoric staubosphere. By elimination, however, its essential difference from the corresponding content of our atmosphere can be reached. Thus, increasingly through the historic period, culminating in our day, metals have been more used in greater and greater quantity. And again, whilst excavations of ancient sites indicate to what extent dusts have been there age-long deposited, what proportion is wind-blown and what settled, is not clearly evidenced.

In addition to metallic dusts—continuously added—other chief dusts in the present atmosphere not greatly prehistorically existent, are those due to combustion and the consumption of fuels. Without even definite knowledge when primitive man

first discovered fire, his use of it would be relatively insignificant, even if first applied at the last inter-glacial epoch—say 10^5 to $1{\cdot}5 \times 10^5$ years ago. A still more modern, yet merely-commencing addition, to the staubosphere, is rubber dust. Considering as chiefly constituting the prehistoric air-dust content: detritus dust from decaying vegetable matter; volcanic dust; rock dust; cosmic dust; sea-spray dust; decaying organic-matter dust (e.g. prehistoric animals); the notable additions made to these by man through history, are metal dusts, and fuel combustion dusts. This addition has increasingly intensified down to our own times, and now increasingly includes additions such as rubber dusts. Excluding volcanic dust, man has chiefly added to the staubosphere, interior earth-crust-originating dusts, to augment prehistoric exterior earth-crust dusts; chiefly artificially-produced carbonaceous and metallic dusts, to natural inorganic and organic dusts.

Present-formed carbon dust from coal could not exist had not prehistoric dust—making rainfall possible—have encouraged the growth of vegetation which, buried for long ages, produced such coal. Our present dust atmosphere is thus indirectly due to the prehistoric dust atmosphere.

Any cumulative suspended dust effect is obviously a question of balance between continuous formation, and continuous removal as nuclei for rain, mist and fog formation. Somewhat similar to that between anabolism and catabolism in living subjects.

Classes of Historic Dusts.

Some attention needs to be given to historic dusts themselves. They may be subdivided into ancient, mediæval and modern, the distinction with regard to the nature of dusts formed being largely similar to that between prehistoric and historic dusts. But, additionally, there will be a difference essentially due to the existence of huge, human populations, and to the respective portions of the earth where, in a general sense, such populations were found respectively.

Whilst any slight difference which would be caused in air-dust content by, or as between, the Stone, Iron, Bronze, etc., Ages as such, would be in the prehistoric period, historic periods only where considerable populations are concerned are now being considered.

In addition to a gradually-increasing dust production of metals and carbonaceous materials, from the ancient period, through the mediæval, to the modern, a geographical selectiveness from period to period, would also exist.

Ancient Historic Dusts.—Those formed in ancient times would chiefly be found—except such already mentioned as both prehistoric and historic—in regions of the earth peopled by ancient civilizations. That is, in far eastern and eastern regions. And although their metallic and carbonaceous content would be far less important than their modern counterparts, there would certainly be a proportion of metallic dust formation. For ancient nations were warring nations. Base-metallic dusts formed, therefore, would be from weapons rather than objects of general utility. Ancient domestic methods contrasted with modern factory methods, symbolize the respective amounts of formed metal dusts. The proportion of noble to base metal dusts formed, would probably be greater in ancient times, for they had more vulgar ornamentation tastes. Also, in addition to the much vaster modern use, base-metal availability has tremendously increased due to scientific advances. Owing to the relative geographical position of these eastern regions, metallic dusts would not, but naturally-formed siliceous or sandy dusts, would, predominate. Consider ancient Egypt. Whilst the contents of museums, and recent spoils of ancient tombs, testifies to the work done in metals, productive—no matter how slowly—of metal dust the fine-blown sand dusts from the Libyan and Arabian deserts, would have accounted for by far the larger proportion of air-dust content. With modifications, this would apply to the ancient peoples of Mesopotamia, and probably the Mongolians or Chinese at the edge of the Gobi desert.

Mediæval Historic Dusts.—The distinction between mediæval and modern would be more marked. For whilst mediævally, warfare continued for its own sake (involving great base-metal production) the great transition to the machine age was, qualitatively, as far off as ever. Geographically further west than the ancient, there would be, mediævally, relatively greater use of base than noble metals, and a sand-charged atmosphere would be largely replaced by a fuel-product-charged-atmosphere. For life-maintenance in temperate regions requires immeasurably more fuel-produced warmth, than in tropical or semi-tropical regions. The chief change in dust formation

from ancient to mediæval periods, therefore, would be chiefly due to change of geographical venue.

Modern Historic Dusts.—In those formative revolutionary years introducing the industrial revolution, a drastic dust atmosphere variation was being gradually, unconsciously, staged. Commencing in southern Wales and England, and, increasing in volume, spreading to new coal-fuel fields in northern England and Scotland—which gradually became the centres of huge metal-making industries—it forced the evolution of engineering practice and theory which, in turn, spread the iron and coal age and its specialised dust production, back through European countries towards the east; and forward to where the New World in the west met the east. The whole world, in this modern age, is in this new iron-and-coal dust grip.

Its historic and actual centre the polluted atmospheres of Britain's great industrial cities. All the evidences are with us, constituting an atmospheric pollution problem of grave urgency, with its serious national health, climate and building-fabric effects.

Some notion of the extent of the above historical variation can be gained in tabloid form, in the severe contrast between English and Mediterranean winter climates. Travelling from former to latter is traversing the drastic distinction between the air-dust content of the modern iron and coal age, and that of the ancient period. With this exception: the steady fall of gritty coal ash or dust on the deck of the transporting steamer is real evidence of the world-wide iron-coal-dust grip. The change-over from prehistoric and historic dust systems is, of course, a continuous gradation which, combined with the indestructibility of matter, emphasizes that a large proportion of present dust systems had their origin, as regards particle content, prehistorically.

The Work and Influence of Dust.

Whilst, through the ages, much prehistoric dust will have continuously settled on land; passed to the sea in rivers; settled in river beds; or directly into the sea, at any given period, a portion of that settled on land will have been again stirred-up into the atmosphere by winds, and such of this as again settled before re-stirring, may have done so over more modern layers. Thus, where old civilizations are excavated, it would not seem just to suppose depth of position to imply

age of dust deposit, in any strictly-delimited manner. This will apply, at least equally, to the intermixture of ancient and mediæval, with modern dusts because the time-span—relatively smaller—the proportion settled in the overlapping series of cycles, will be less than in the case of prehistoric dusts. The implication is a mixture of atmospheric dusts at any time. Whilst, therefore, it may be supposed that prehistoric dusts still persist in the earth's atmosphere, it is likely that ancient and mediæval dusts persist still more. Dust particles, therefore, visible or invisible, which we breathe, scatter, or scientifically count, were many probably existent in almost their present form ages before man appeared, and more, quite as old as the earliest history. A large proportion must have been in all conceivable places and circumstances owing to constant large or small-scale movement, to which they have, necessarily, been as long subjected. As rate of formation ; formation period ; factors preventing scientifically-controlled settling, are not exhaustively known or computable, and the agents causing atmospheric redistribution are not seriously commensurable, the proportion of settled to moving dust cannot be stated. It can be postulated that all dust formed or existent exceeding the maximum amount retainable by the atmosphere, must settle, though its particle population must constantly and continuously change. Such maximum would, naturally, be determined by the amount possible to man to breathe, before asphyxiation ensued. Emulsions can be prepared consisting of 99% disperse phase, and there seems no obvious reason—save formation of mist, fog and precipitation intervening—why aerosols should not exist in similar proportions. Even with a particle content of 250,000 per cubic centimetre, of average radius one micron, but one millionth of the space would be occupied by the dust.

At every moment, in every place, there must exist an unstable balance between dust settlement and re-dispersal, respectively assisted or prevented, wherever men or animals are, by natural, artificial or mechanical movements. Gravity, wind, rain, landslides and similar natural movements will be effective. Some, too weak to operate alone, e.g., a zephyr, may do so after movement initiation by animal or human agency. Thus such a zephyr may lift fine dust, after independent initial disturbance. Prehistoric particles "rubbing shoulders" with mediæval and modern ones, may anywhere be

quietly settling, when a slight breeze or other atmospheric impulse from a hundred-mile-distant storm may quickly arrest, affect, or totally-reverse the fall rate before particles which would have settled, have done so. A hundred yards away, a slight breeze may have lifted pollen dust, which, slowly commencing to settle does so, owing to air currents, an inch, yard, or mile away, in any conceivable direction. Such tremendous, earth-wide give and take, day and night, continuously progresses. Myriads of dust particles, of all kinds and descriptions, as the everlasting sport of the meteorologic elements.

But this vast earth-atmosphere filter passes first the *larger* particles, acting oppositely with regard to the material filtered, from all artificial filters. Doubtless the generic manner in which the gravitational effect operates in the reverse direction to the capillary effect—and a striking distinction. Like the air, also the sea, the resultant being that finest particles remain longest suspended. This characteristic, assisting visibility, additionally helps man less obviously by allowing him to act as though the air had no appreciable dust content. On the contrary it presents possible access of very fine, dangerous dusts to the inner lung tissues, whereas larger particles would be eliminated by the bronchii. It may, therefore, suggest the presence of, at least some dust, as physiologically beneficent.

A small piece of rock fallen to the earth further disintegrates *in situ*, until broken into fine particles. These will be periodically windswept, when not raising, rolling them over to corrade each other. A continued, intermittent, mutual grinding operation, of varying intensity, number, and disposition of participating particles, is produced. This entirely-spasmodic, physical trituration, continually obtains over the earth, as an obscure degradative process of solids towards dusts. Where, originally, a small disintegrated mass, unlevitated by wind of given force, is subjected thereby to levigation, it will be raised later, consequently, by wind of similar given force, independent of other similar assistance. This mutual *in situ* trituration, therefore, not merely produces degradation, but the potentiality for dust-cloud formation. Whenever wind can raise dust cloud from awaiting particles, mutual attrition of the constituent particles must result. For, within a cloud's ambit, the angular motion of given particles will be determined by their size, shape, and density; air-pressure irregularities; and varying potential settling-rate. Particles will thus suffer

continued mutual impact, causing further degradation. Even where dust particles eventually become so fine as to move with the air as though molecular, mutual attrition must proceed, since molecules are constantly impacted. Lack of definite knowledge of the finest dust dimensions presupposes continuing disintegration due to mutual attrition, of very fine ones. For even molecules suffer dissociation.

The effect in nature of attrition by dust-clouds themselves, on solid formations, is everywhere evident. Thus, pillars formed by the constant peripheral removal of their constituent materials are fairly common, some having been very recently observed in the Libyan desert (113).

Dust is continuously settling on land and sea, in either locations where formed, or others, dependent on the intermediary operation of other factors. River-action in changing land-area contours, is only of greater extent, not importance, than the equivalent work of dust. For, by settling, and being raised and wind-carried, dusts are everywhere active in affecting land contours. Furthermore, dust settlement on water surfaces constitutes a very gradual transference of solid matter from land to sea. The chief agencies in accomplishing this are rainfall and gravitation, assisted by wind. Whilst, therefore, wind assists vaporization in carrying water from sea over land, the work of gradually lowering the land surfaces and filling the seas is contemporaneously performed by the return of such vaporized water, and by wind assisting gravitation in carrying dusts from land to sea. Dust is a great assistant of wind and river systems in this respect. Whilst, therefore, in the production of dusts weathering and corrasion are gradually levelling all solid earth contours, filling of the ocean with solid matter, keeps pace. A very important reality: with the resultant general order of dust removal being from the surface downwards, and the general order of ocean settling being *vice versa*, causing a turnover of the earth's upper crust from land to sea, as of concomitant importance. Historic dusts will tend, therefore, in the ocean beds to lie under prehistoric dusts. Thus, both man and nature are turning over the earth, via dust formation, as gardens are turned.

Slowly, but cumulatively, therefore, man assists nature to ventilate and turn over the essential material—source alike of dusts and his biological complement—from which his generations are formed.

CHAPTER III

DUST IN NATURE

The Natural Inception of Dust.

Dust is almost certainly the most ancient and original form of solid matter known to man by experience or scientific reasoning.

The planitesimal and meteoritic theories of the earth's formation, postulate the frictional agglomeration of cold meteorites, millions of which each day still reach the earth, disintegrating to dust. In all probability, therefore, meteoric bodies are built from dust, so that dust was the earth's basis before its formation. Furthermore, Arrhenius suggests that meteorites—many of which are built from rounded grains—are compacted of such grains shot from the sun. The original formation of dust *on* the earth, was only made possible by the shrinking of the meteoritic mass causing the extrusion of primary rocks—the basis of dusts.

If the theory of Helmholtz and Kelvin of shrinking used to explain the production of solar energy, be true (though it only account for a solar life $4 \cdot 6 \times 10^7$ years) then the parallel of dust production may be applicable to the sun. And, in any case, the more modern solar energy theory of element-transmutation, or mass-annihilation, involves a shrinking process be it but 1% of mass in $1 \cdot 5 \times 10^{11}$ years.

Dust therefore, seems to be the source of meteorite formation; the product of meteorite disintegration; and a primary product of the earth's disintegration. It is fundamental. It is involved with the production of energy in the universe; contemporary with the first conditions on the earth, necessarily precedent to life of all kinds.

Natural Exhaustive Dust Classification.

That vast, heterogeneous, physical and chemical natural dust, formed by natural processes alone may be classified as:

(1) Deposited earth-formed. (3) Circulating cosmic.
(2) Deposited cosmic. (4) Circulating earth-formed.

distinction between deposited and circulating being that the latter is dispersed as aerosol, the former settled as aerogel.

(1) *Deposited Earth-formed Dusts.*—Hopeless through the earth's historic period, it would become insuperable, prehistorically, to compute the respective amounts of cosmic and earth-formed dusts. Cosmic dust, it must be remembered, has probably continuously fallen on the earth through countless ages. Unless it can be stated that cosmic dust is never, nor has ever been siliceous, it is impossible to conclude what proportion, even approximately, of a common dust like sand, is respectively cosmic and earth-formed. But, actually, many meteors and meteorites are almost wholly stone, though such may generally contain chondrules and be permeated with specks of iron. If this applies to the earth's most common element—silicon—much more so with regard to the less common, often so sparsely scattered that their sum total, unlike sands, could not be approximately computed.

This class will have all originated from earth, or earth-objects, initially or subsequently formed through the earth's history, organic or inorganic, or from initial or subsequently modified atmosphere by settling (excluding cosmic content). This uncountable dust population will comprise particles—of whatever size, shape, or physical or chemical constitution—each with different life history from all its fellows regarding (*a*) manner of origin, (*b*) period of origin, and (*c*) subsequent history.

(*a*) *Manner of Origin.*—Some particles will have been formed by weathering, others by chemical corrosion; solution and evaporation; or trituration of many different kinds. Still others by recombination rather than degradation, and deposition from the earth's original rainfalls.

(*b*) *Period of Origin.*—Each moment of time, since the earth's formation, has probably added its quota to the present earth-formed dust content. This suggests an incalculable age-gradient, in turn implying an incalculable deterioration-gradient. For a particle of any material—in close or indifferent contact—under varying natural impulse—with others, and with possible oxidation or other effects over a million years

must vastly differ from its original state, compared with one but just weathered from its original rock.

(*c*) *Subsequent History*.—This is likely to confer greatest particle difference. One particle formed from the earth's beginning may, by interlude, have lain wind-undisturbed for a hundred thousand years, whilst another but a thousand years old has been wind-raised and rain-deposited half a million successive times. Another, new-formed one, may have hidden in a corner of the Alhambra for a month, and be now in the White House, whilst an ancient one may have spent thousands of years passing from one to another Saharan dune. It should be insisted that the great size and shape variation of particles is largely due to this cause, and that—other things being equal—the smaller the particle the more varied and spectacular its history; the more varied and frequent its chances of further size-reduction, with the result either (i) that some portion of the particle must be dissolved or vaporized, or (ii) a further, new particle, must be formed from the original one. If (ii) is the more usual then, unless prevented by some general prevention law, new particle formation with an ever-multiplying dust population formation, must be proceeding. If silicon may be formed from electrons in interstellar space—additional to disintegration formation from larger units—the converse would be disintegration right down to molecular dimensions.

Earth-formed dusts will obviously and constantly vary in number and type. For, just as they will be augmented by settling from circulating dusts, they will be a source supply for adding to circulating dusts under wind or other dissemination movements. They will thus have the characteristics of a relatively stationary zone within a moving system rather than of a self-sufficient, absolutely stationary delimited system.

(2) *Deposited Cosmic Dusts*.—Their origin, so far as known, will be meteors, meteorites, comet-tails, fireballs and bolides (which, larger than meteors penetrate the atmosphere further).

Nickel and iron will predominate in metallic meteors, etc., whilst non-metallic ones will give stone dusts, iron particles, and chondrule particles. Thus such dust will be equally, metallic and stony; almost complete nickeliferous iron; or stony with scattered nickel and iron grains, from siderolites, siderites or aerolites, respectively, in each case subject to combustion and oxidation changes. Of the 2×10^7 meteors one

estimate of the daily meteoric entrants gives, practically all are friction-disintegrated before reaching the earth, in a period, generally of seconds or minutes, though the larger fireballs and bolides may enter at a height over 100 miles and continue considerably less than 20 miles. Meteorites, far the largest entrants, average but about 10 per annum. The effective duration of the meteor shower of October 9th, 1933, was 4 to $4\frac{1}{2}$ hours, the stream's thickness where transversed by the earth being roughly 3×10^5 miles (171). Meteors averaging say, several milligram weight, that of meteorites may vary from pounds to tons. In 1865 100,000 meteorites were included in a fall. Meteors, perhaps 0·125 to 0·25 cm. diameter, are completely disintegrated in the atmosphere. Their arrival from outside the solar system is thought first evidenced by the Joint Telescopic Meteor Survey of Harvard and Cornell Observatories who observed great streams of meteor dust, some seeming to travel at 140 miles per second. Some of the smallest were no larger than grains of sand. Meteorites may be massive on striking the earth despite dust losses in travelling.

The reality of meteor dust is evidenced by that from a meteor observed about dawn on March 24th, 1933, over a large area of the south-west U.S.A.—C. C. Wylie (121). Its dust-cloud remained long visible, and like all it was totally air-consumed. Meteors in the earth's atmosphere have a least speed of 11·15 km. per second, but their speed in the earth's apex region is 71 km. per second—Willard J. Fisher (122). The material of comets' tails, much already fine dust, is probably of similar composition to meteors. F. A. Mallon and W. Schriever of University of Oklahama theorize that a large comet struck the earth from 1×10^5 to 1×10^6 years ago, devastating $1{\cdot}9 \times 10^4$ square miles where are now north and south Carolina, shattering itself. Prodigious dust would be produced by such an event, as also when depressions are made by arriving meteorites. Though estimated that meteoric dust adds but a layer of, say, 0·025 mm. in 10^6 years, to the earth, as fossilized meteorites are unknown, this must represent the accumulated dust from, say, 2×10^7 meteors each 24 hours. Evidence of the cumulative effect is the meteoric iron-dust found in sea-bed silt very far from land; in hailstones; and in Alpine, Swedish and Siberian snow. Data concerning silica glass from meteorite craters at Wabar, Arabia, gives an idea of nature and particle size of such dust. In addition to

many vesicles (suggesting colloidal origin) spherical black particles of nickel iron from ·3 to 140 micron diameter, to the estimated number of 2×10^6 per c.c. are found—L. J. Spencer (117). As both air and sea-bed carry cosmic dusts they must surely be intermediately earth-deposited.

At 2×10^7 per day addition rate—though N. Lockyer estimates that 20 times this number may arrive—and an average weight of, say, 0·005 gm., the daily meteoric complement will be 10^5 gram, or, in a historic period of but, say, 6,000 years, about $2{\cdot}2 \times 10^{11}$ gram, total addition. Supposed all consumed to smoke or dust and weight doubled, say, by oxidation, the addition will be $4{\cdot}4 \times 10^{11}$ gram. Air-deposited solid over Great Britain during 1931–32 was approximately two-thirds ton per square mile each 24 hours (116) giving a total of, say, 6×10^{10} gram per day, or about one-tenth the cosmic addition in, say, 6,000 years (excluding meteorites, fireballs, etc.). The air-deposit figure for 100 years would be $2{\cdot}2 \times 10^{15}$ gram, and may be regarded as including all other industrial countries owing to their shorter existence as such, and the figure being too high an average for Great Britain over that period. Cosmic dust would require 60 million years to reach this amount. Whilst, therefore, through the industrial era dust deposition will be superlatively industrial relative amounts of cosmic and industrial dusts totally deposited may be of similar order, since millions of years would see no industrial deposition. The present damage and inconvenience by common consent now caused by industrial dust will, therefore, be some measure of the effect of accumulated cosmic dust, since its time-long accumulations will be constantly swept-up to mix in the air with the continuing daily additions.

(3) *Circulating Cosmic Dusts.*—These will be formed from new meteoric disintegrations, and wind-raised, diffused, or convection-raised meteoric deposits. The period of new additions represented by still-dispersed dust will depend on rate of fall of the disintegrated dust. For the less the number of disintegrations whose products are suspended, the quicker the average settlement speed. Fall rate depends upon disintegrated particle-size and density, and atmospheric density (in accordance with Stokes' (6) or Cunningham's (8) laws; or the normal gravitation law). Hence the greater the proportion of elements of lesser atomic weight in meteors, and the greater the disintegration (i.e. the smaller the particles) the more

numerically dense, at any time, will be cosmic newly-formed circulating particles. Though indeterminate, the values may be supposed constantly altering, immediately or recently-formed meteor dust constantly varying with meteor chemical nature, and degree of disintegration. If smoke is first formed agglomeration may precede disintegration, though rarefaction of the stratosphere tends to suggest absence of combustion. However the largest proportions of free ozone lie between 15 and 50 km. height—Gotz, G. M. B. Dobson, and A. R. Meetham (123). Though never having introduced new elements to the earth, or its dust load, meteorites have been shown to introduce about 34 of the known elements. Wind raised deposited cosmic dust will have its youngest members older than the oldest newly-introduced circulating cosmic dust, and its oldest may be any age up to world-age. The wind-raised fraction will have reached ultimate state of division, except for earth-formed or other cosmic adherents, which may separate therefrom on dispersion, whilst the newly-formed may be still either aggregating or disintegrating. A further important distinction between the two classes, is that one is introduced to the air from the stratospheric limb, the other from the terranean. Outer, and inner introduction, respectively. The former, newly-disintegrated, will therefore have much further to settle, than the latter, wind-raised, to re-settle. Subject to wind-checks, and mingling air-current action, and varying fall-rates due to differing particle size, there will be two spheres—an upper and a lower—the former carrying newly-disintegrated, the latter wind-raised deposited, particles chiefly. With the latter in the lower troposphere where settling is quicker owing to restricted range, this effect will be assisted by return to the deposited state by forming rain-drop nuclei somewhat counteracted by inverse variation of air density with height. Save in their primary passage through the lower region, newly-disintegrated dust particles will not be available for rain formation till after its first settling, i.e. when converted to deposited cosmic dust. Even in default of all other particle nuclei, meteoritic dust would still provide a continuous medium for rainfall. Meteors, meteorites, etc., are therefore important for rainfall, and thence, for animal and vegetable life, in similar order to that of the sun in vaporizing water from the oceans. Newton's speculation (117*a*) that comets' tails (now believed composed of dusts) may supply an

important substance to the atmosphere is notable. That substance may be dust. Doubtless winds—particularly higher ones from equator polewards—will blend the two cosmic dust varieties, respectively rising and settling, promoting homogeneity of particles and settlement. Deposited cosmic dusts will, likewise, be constantly moved in deposit-location from point to point over the earth.

(4) *Circulating Earth-formed Dusts.*—These will chiefly share the lower troposphere with one class of circulating cosmic dust, as noted, save such as may have never settled from the earth's formation. Largely siliceous as compared with the metalliferous cosmic dusts, they will yet contain some metal dusts. There will thus be chemical overlapping of the differently-classified dusts of the lower troposphere. But a distinct particle size differentiation will probably exist between the two classes, for whilst the earth-formed owe their origin to successive physical degradations, the cosmic are formed by chemical action in meteoritic combustion due to gravitationally-controlled friction. Physical initiation implies larger to smaller particulation ; chemical, smaller to larger. Extraneous energy sources, therefore, are used immediately in the former case, and continuingly, intrinsic energy sources initially in the latter case (if smokes are first formed) succeeded by extraneous energy operation in degradation from aggregates. But if completely aggregated, prior to degradation, cosmic have but little particulation to undergo, contrasted with earth-formed units from their origination. So that, even after complete aggregation, cosmic units may be in so fine a state of division that earth-formed units never, even eventually, attain. Though a proportion of either class will be, probably, particulated towards molecular dimension, such proportion is likely to be much less with earth-formed dust, though in absolute amount, it will probably be much greater than with cosmic dusts. The important implications from this probable differing particle size may be (*a*) that the larger earth-formed particles attract and hold to themselves smaller cosmic particles, in accordance with Aitken's differentiation process (28) which he applies to fog droplets and (*b*) more rapid settling of attached, than unattached, cosmic particles. By a cushioning effect, (*a*) may retard collision and mutual further disintegration between the larger earth-formed particles, in cases where disruptive approach does not operate. A possible explanation of self-electrification

of moving particles is that the charge divides itself between larger and smaller particles. Adherence under (*a*) would neutralize many charges. Adherence would also modify charge if, following another explanation of chemical difference origin, this were thereby modified. Such possible electrical variations due to large-small particle adherence, may account for very varied potential gradients at different places, in the lower troposphere. If cosmic particle constitution can be assumed roughly similar everywhere earth-formed particles are certainly very chemically different in different localities. In the British Isles the latter, larger, particles will be more carbonaceous; in Egypt more siliceous. This strong variation in one particle factor may give rise to different degrees of electrical tensions—other things being equal. A distinct question is whether the huge electrical tensions created in sandstorms depends upon simultaneous wind-raising of huge quantities of both cosmic and earth-formed dusts, or whether such high tensions would arise if either dust class were solely raised.

Fusion of the Various Classes.—The separate characteristics implied by division of the natural staubosphere into four classes, cannot of course, operate independently. The world dust-system is a living and organized whole of inter-dependent parts. Whilst dust is constantly and steadily pouring upon the earth from space, the unceasing "rain" normally invisible, winds are as constantly lashing through the atmosphere and back to the earth in a never-ending cycle, that already deposited of whatever origin. Life would undoubtedly largely perish on cessation of this organized dust system in the absence of some now-unknown, substitute to cause precipitation. For, even with commonly high enough supersaturation to generalize condensation on ions, these, at about 10 per c.c. per second, rapidly decrease with height. Superimposed upon this dust cycle, supplementary dust is ever being added to mingle therewith. Every varying in relative quantity from class to class; in relative particle number and size content; in relative physical and chemical nature of included dusts, this latter is dependent on civilization continuation, on new materials man constantly introduces, accelerating with scientific progress, discovery and invention. Such additions negligible a hundred years ago, still become ever more frequent, e.g. tobacco and rubber dusts. A small continuing change arises by cessation of dust-forming agencies displaced by the new entrants.

The world dust population therefore is virile and kinetic rather than static, much more so in regions of western progress, though other regions will feel a reflex action therefrom.

Dust and the Geographical Homologues—The four geographical homologues have fundamental importance for the earth's dust distribution. The first, that land masses are chiefly accumulated in the northern, and sea areas in the southern hemisphere, means that, in so far as the world-wind systems do not mingle them, southern hemisphere-dusts will be chiefly inorganic, non-industrial, hygroscopic and unchanged from remotest times; whilst northern hemisphere-dusts will be modified by considerable organic, industrial, non-hygroscopic dusts, and will have been constantly changing from the remotest times. A practical result of this homologue differentiation is the distribution of such diseases as goitre and cretinism due to iodine deficiency. For thyroxin, largely derived from sea iodine nucleisation decreases with distance inland, and such diseases are selective in mountainous regions —J. Alexander (110).

The second homology—the triangular shape of geographical units, solid or liquid, will by modifying wind systems, modify dust distributions and their concomitants. It will also have the effect of locating modern dust formation still further north of the equator.

The third homology—the continuance of the land belt almost around the northern hemisphere, means that modern, industrial, organic dusts will be modified in minimum manner by inorganic, hygroscopic dusts, as the former circulate from country to country.

The fourth homology—that land areas are almost always antipodal to sea areas, means that the dust in the atmosphere at any point over the earth is generally, essentially different from that over a point antipodal thereto.

The general homological effect is the probable separation of dusts on the earth—circulating or deposited—into two great classes, fundamentally different in physical and chemical nature (quite distinct from size). The consequent repercussions on plants, human beings and animals, must be far-reaching and enormous, though modifying tendencies such, e.g. as the formation of nuclei from the sulphuric acid of city smokes by sunlight, will obtain.

THE THREE SIZE ZONES OF THE STAUBOSPHERE.

The staubosphere is likely to consist of three different dust zones differentiated by particle size variation, atmospherically intermixed, the members of each being theoretically determinable by their respective settling-rate control law (under quiescent conditions). Thus particles of radius greater than 10^{-2} cm., will have velocity determinable by the gravitational law; particles less than 10^{-2} cm. radius and over 10^{-4} cm. radius by Stokes' law (6) (Rayleigh (7) having shown Stokes' law inapplicable for water droplets over 10^{-2} cm. radius); particles less than 10^{-4} cm. radius by Cunningham's law (8) a modification of Stokes' law (*cf.* the Scientic Study of Dusts).

The Cunningham modifying factor for Stokes' law has to be applied where the fall velocity of any particles is greatly affected by the ratio between particle-size and mean free path of molecules of the dispersion medium, so that the ratio begins to approach unity. Thus 10^{-4} cm. radius is regarded as the lower limit for Stokes' law application, because at normal temperature and pressure, the mean free path of the gaseous molecules of the air is of the order 10^{-5} cm. But as mean free path of air gas-molecules increases with rarefaction, i.e. height, at a height when it is, say, 10^{-4} cm., the velocity of fall for particles of 10^{-4} cm. radius will be considerably greater than with a smaller mean free path of air gas-molecules of 10^{-5} cm. Air density is often ignored in applying Stokes' law, which ignores dependent quantities (e.g. rarefaction). Hence the lower particle radius of limit of 10^{-4} cm. may be considered in all cases.

Considering each particle zone separately.

The particles of that obeying the normal gravitational law will fall, under acceleration, 32 ft. per second, per second. But the characteristic of Stokes' law settlement is terminal velocity, i.e. no acceleration.

The characteristic of Cunningham's law settlement can be shown. Since, according to Halley's law (124) at a height of 6 km., the number of atmosphere molecules will be about halved, their mean free path may be regarded as doubled. The Cunningham modifying factor: $1 + A\frac{L}{r}$ in which L is the mean free path, will therefore, be practically doubled. Hence

the velocity of particles obeying Cunningham's law at 6 km. will be about twice their velocity at ground level.

Between these levels owing to the rarefaction (hence density) gradient of air (the medium), the particle velocity will decrease as height decreases.

The characteristic of the Cunningham law settlement is, therefore, a deceleration.

Where therefore, as in the staubosphere, particle size may be regarded as the criterion, the three zones of the staubosphere will be (1) that whose particles settle under gravity with rapidly-accelerated velocity, (2) with slow, non-accelerated velocity under Stokes' law (6), and (3) with slower, decelerated velocity under Cunningham's law (8). This divides the zones according to their chief respective characteristics of settlement. With regard to relative velocities, zone (1) will have by far the greatest velocity, (2) considerably less, and (3) velocity less than (2). With reference to dust particles which originate as smokes, forming aggregates whose density (though their size may not) brings them within the ambit of either Stokes' or Cunningham's laws, smoke particles will probably exclusively add to one or other of these two zones.

IMPLICATIONS OF SIZE ZONIFICATION.

When atmosphere mean free path has increased to 10^{-4} cm., particles which in a denser medium obey Stokes' law will commence to obey Cunningham's law. For the particle radius being then of similar dimension to the mean free path of the air molecules, particles will have increased mobility and start to move between the molecules, the Einstein brownian movement formula only holding from 760 to 10 mm., pressure, below which—according to de Broglie (106)—a considerable increase in particle speed and amplitude occurs (for the above reasons) only strictly applying when particle radius r is small compared with $\frac{L}{r}$, L being mean free path of medium molecules.

Above an atmospheric level of about 10^{-4} cm. mean free path, or say 10 mm. pressure, there are, therefore, likely to be but two particle zones, viz. obeying Cunningham's law; and obeying the normal gravitational law. Those of the first zone which, at lower levels, would obey Stokes' law will have greater velocity than smaller ones which would always obey Cunningham's

law. In the neighbourhood considered, however, such larger particles will also have a deceleration downwards to the 10^{-4} cm. level. Below the 10^{-4} cm. mean-free-path level, the relative speeds and accelerations (or otherwise) of the normal zones (1), (2) and (3) will apply. Whilst the atmospheric molecular distribution will, after Halley's law, be similar to the Perrin (17) "giant molecule" arrangement, the thermodynamic explanation of osmotic pressure across a semi-permeable membrane, shows Perrin's values not to hold for heavy concentrations. But the Perrin distribution may be regarded as holding for the atmosphere, though modification may occur from particle electrification as suggested by Burton (458) and from the great atmosphere depth as contrasted with Perrin's experimental conditions—Porter and Hedges (459).

The tendency, explained in the Scientific Study of Dusts section, for the three zones to pass through one another due only to particle-size variation, will have large effects on the particles themselves, not possible if they all obeyed the same settling law. The 10^{-4} cm. level where the three-zone effect passes into the two-zone one, will be difficult to fix, for whilst there will be a large region higher than this level since molecular content gradually falls from, say, $6 \cdot 0 \times 10^{23}$ per c.c. to—according to J. H. Jeans—$3 \cdot 6 \times 10^{5}$ per c.c. this does not display the intermediate gradient.

As the different zone members intermingle they will constantly collide due to their different velocities. Consider three particles 10^{-5}, 10^{-4} and 10^{-2} cm. radius respectively, representing the three zones, all starting from rest at 6 km. height. In one second they will, respectively, fall 0·00036, 0·012 and 480 cm. (supposing unaccelerated velocity for the first two) the velocity ratios being $1 : 30 : 1 \cdot 4 \times 10^{6}$. The fastest particle taking inappreciable time to fall 6 km. may be here ignored. Near ground level, the slowest particle—obeying Cunningham's law—will owing to mean-free-path variation, have reduced speed of 0·00024 cm. per second, changing the ratio to 1 : 50, since the Stokes' law particle will retain throughout constant velocity. Slowest particle average speed throughout the fall may be 0·0003 cm. per second. The slowest particle will require 60 years to settle 6 km. but the faster particle only one and a half years (assuming quiescent conditions).

Whilst, therefore, one 10^{-5} cm. radius particle settles through 6 km. to earth, 40, 10^{-4} cm. radius particles will do so, each

successive one starting to fall after each preceding one had finished. Supposing none but these 41 particles, and all taking the same path, there would be 40 — 2, i.e. 38 collisions between one slow particle and 38 faster ones. The slow particle would, therefore, suffer 38 impacts; the faster particles, one each. The kinetic energy of a 10^{-4} cm. radius particle moving at 0·012 cm. per second (of unit density) is approximately 3×10^{-16} erg. That of a 10^{-5} cm. radius particle moving at 0·0003 cm. per second, approximately $1{\cdot}87 \times 10^{-22}$ erg. The energy in such collisions, therefore, supplied by the faster particles will be of the order 2×10^{6} times that supplied by the slower particle. Thus, in falling under the given conditions over the given period the slower particle will submit to $38 \times (2 \times 10^{6})$, i.e. $7{\cdot}6 \times 10^{7}$ times the impact energy suffered by a faster particle whilst falling. Is such energy transformed into electrical, or heat, energy, or spent in disintegrating the particles themselves, or in a partition of those modes? Similarly considering fastest 10^{-2} cm. radius particle, and the 10^{-4} cm. radius faster one, 4×10^{4} former will collide with one latter in one and a half years; the latter suffering $5{\cdot}6 \times 10^{17}$ times the kinetic impact it imparts to each of the former. This hypothetical case would be generally extended if the various sizes were always supplied in the same proportion; the atmosphere were quite still; and available space were divided into tracks of circular cross-section 10^{-2} cm. radius. Such conditions cannot, of course, conceivably apply. For in the staubosphere particle size will vary in a continuous and transitional manner, and all kinds of meteorological disturbances will intervene. But the figures indicate that the finest particles will be the butt of the members of the other two zones as they pass through, they themselves possessing minimum kinetic energy and being most affected by the greater, and maximum, kinetic energy of the others. The smallest particles will fall with decelerating velocity; the medium and largest with steady, and accelerating velocity, respectively. The medium zone particles will, therefore, have a relative acceleration with respect to the smallest, but the largest particles will have a positive acceleration of their own. The relative acceleration of smallest with respect to medium zone particles will only obtain below the 10^{-4} cm. limit, for above that the two classes become merged, as explained.

Consider an atmospheric layer 1 km. deep below the 10^{-4} cm.

level. It will contain greater or less total particles dependent on height in accordance with Perrin's distribution, but, in any case, can be supposed a self-contained region. The respective settling times of the particles of the three zones contained therein will be in ratio, say, $1 : 40 : 1{\cdot}4 \times 10^6$. Substituting the whole indefinite, atmospheric depth for the 1 km., this ratio may be regarded as that of the amplitudes of movement of the respective zones in equal, or unit time. Only the two smaller zones are of comparable order. Since the larger of these requires one and a half years for its particles to settle 6 km., the smaller, with a fall-rate of but 10 years per km., is relatively stable. In addition to this practically stable state (under quiescent conditions) of particles 10^{-5} cm. radius or less, such have also a decelerated velocity set up against the gravitational pull.

For the purposes of the varying, rapidly-changing, state of the atmosphere, therefore, it may be said that such particles less than, say, 10^{-5} cm. radius, never settle, but are more or less permanently retained in the atmosphere. If augmented numerically at a greater rate than depleted by slow settling, this staubospheric zone will be an increasing one, provided other means, e.g. rain-drop formation, do not remove them.

Zone amplitude is therefore important, indicating that some particles remain inappreciably suspended ; others appreciably ; and yet others practically permanently ; in the atmosphere. Certain other considerations arise. For Clerk Maxwell in 1870 showed that small particles were repelled by light rays with intensity proportional to the exposed surface, whilst Ehrenhaft (79) showed that of particles 10^{-4} to 10^{-6} cm. diameter, some are repelled, some attracted by intense electric arc light, the velocity of displacement being increased by increasing light intensity or diminishing gas pressure. If the sun's light effect on particles in space is similar, their motions will be similarly affected. The higher the particles, the more intense the light and the less the gas (dispersion medium) pressure, hence the greater the velocity of displacement. Showing that the higher, the more active the particles, which allied to increased mobility due to mean-free-path increase, may cause—as one result—enhanced frictional electrification, probably still further intensified because, as de Broglie observed (80) uncharged smokes and clouds (by analogy dusts) are charged by exposure to radio-active substances. Further,

since anything electrifying the air (in this case the particles) is, according to Lodge (81) most effective for flocculation; particles may be selectively driven together by their own charges, despite the approach and repellent rotation (as seen ultramicroscopically) of similarly-charged particles. Furthermore Pfaff (510) has shown a 59% flocculation increase over normal, for dust particles immersed in ultra-violet light from a quartz lamp at 50 cm. distance. Decreasing particle size allied to increased agitation (for above causes) with increasing height, tends to produce quicker flocculation—Bjerknes (82). Langevin (85) has shown that at a given pressure, the velocity of a gas molecule in striking another is proportional to the field intensity, and this may apply to larger charged particles. Further factors which may apply are the more rapid movement of particles in concentrated than dilute systems, according to Zsigmondy (96); and with decrease in medium viscosity —Svedberg (97); whilst Millikan (27) has shown that particle displacement at low pressures may be 50 to 200 times that in gases, normally, when in air, it is 8 times that in water.

Kinetic Energy and Disintegration of Particles.—The kinetic energy of collisions may be utilized as a self-disintegrating force. For whilst the radius ratio is but 1 : 10, the kinetic energy ratio is 1 : 2,000,000, between the two smaller particle zones. It may, otherwise, be transformed into cohesional energy resulting in adherence of smaller to larger particles. But as, partially, it will almost certainly be transformed to electrical energy, some disintegration may be also regarded as consequent. Blacktin and Robinson (126) show that 0·031 gram of coal dust of maximum particle size about 4×10^{-3} cm. radius generates in, say, 5 seconds 0·0002 microfarad at 4,300 volts, blown at a speed of approximately 30 miles an hour. Also Blacktin (127) and particularly W. A. D. Rudge (128) have shown that such self-electrification may be supposed more or less general. Crowther (76) states that a gas may be friction-ionized against solid or liquid surfaces, "small" ions so-called by Langevin (76), Wellisch (76) and Loeb (76) of velocity about 1 cm. per second positive or negative, being formed from the gas molecules, the solid or liquid particles becoming "large" ions up to microscopic dimensions, with velocity $0 \cdot 3 \times 10^{-2}$ mm. per second—de Broglie (77). Such large ions are like charged dust or smoke particles carrying generally 1 electron. Whilst such ions are, *ceteris paribus*,

diminished by collision and recombination (increased in presence of solid or liquid particles) in nature, the friction due to the constantly moving particles is likely to create more generation than re-combination.

The energy of impact being considered is, of course, due indirectly to the gravitational factor. It may be supplemented by mutual attraction due to electric charge carried.

The probability of disintegration is explained by analogy with the theory of " disruptive approach " or Roche's effect—1848—regarded by Chamberlin as the formative cause of many meteorites. To the effect that when cold stars collide in space the heat suddenly generated would scatter their contents explosively, whilst grazing collision would only cause their revolving round a common centre, strict application to particle collision may be prevented by the superlatively greater effect of the surrounding air in their case. But in regions of great atmospheric rarity this condition may be regarded as removed. In the high atmosphere, therefore, particle collision is likely to result in shattering and disintegration with continual smaller-particle formation; in lower regions—where mean free path is less than particle diameter—the generality may be grazing collision and mutual rotation. But in these lower regions " disruptive approach " may apply, so that collision would not be necessary for shattering. Thus a particle exerting on an approaching one a greater attraction than the latter's own internal layers in the opposed direction, would explosively shatter it owing to the violent expansion of its internal moisture. Smaller particles, particularly if hygroscopic, are likely to be disintegrated on the approach of larger ones. Since continuing size variation will be general such " disruptive approach " may be the rule throughout the staubosphere, promoted by the intermixing of particle zones. Since the majority of particles concerned will be invisible, so will the effect, tending to produce still smaller ones. It may account for the sudden disappearance of particles in the ultramicroscopic field, the size-reduced products falling from visibility.

The justifiability of applying " disruptive approach " by analogy from extremely large to extremely small objects, is strongly supported by observations of W. B. Hardy (521) of the catastrophic nature of the forces liberated by the mere formation of an interface between two phases. He microscopically studied the contact of a drop of blood with a clean

glass slide as the interface was formed, noting the consequent explosion of blood corpuscles leading to coagulation. An interfacial phase of force—perhaps an electrical double-layer—may similarly be set-up where the circumferences of particle force-fields meet, similarly exploding these " corpuscles."

Dust Auto-Electrification and the Earth's Charge.

If coal-dust density be taken as 1·5, the number of particles of 4×10^{-3} cm. radius in 0·031 gram (126) is about 10^5, and the quantity of electricity generated being $(4 \cdot 3 \times 10^3)$ (2×10^{-4}) (10^{-6}), i.e. $8 \cdot 6 \times 10^{-7}$ coulombs, or $8 \cdot 6 \times 10^{-8}$ e.m.u., absolute —supposing 4×10^{-3} cm., is the average particle radius then the charge per particle is $8 \cdot 6 \times 10^{-13}$ e.m.u., absolute. The electron e being $1 \cdot 6 \times 10^{-20}$ e.m.u., each particle carries approximately $5 \cdot 4 \times 10^7$, i.e. 54,000,000 electrons. From experiments with lycopodium spores before extraction by organic solvents, and after (when their mass was halved with inappreciable change in size or form)—Blacktin (127) showed that total electrical charge varies directly as total surface area exposed. The total area of 10^5 particles (0·031 gram) of 4×10^{-3} cm. radius, and spherical, is 20 sq. cm. The total area of 5×10^9 particles (number of 10^{-4} cm. radius in 0·031 gram, supposed density 1·5) is 625·0 sq. cm.; and that of 5×10^{12} (number of 10^{-5} cm. radius in 0·031 gram) is 6,250 sq. cm. The total charge on 5×10^9 particles would therefore be $8 \cdot 6 \times 10^{-7} \times 31 \cdot 25$, i.e. $2 \cdot 7 \times 10^{-5}$ coulomb; and on 5×10^{12} particles, $8 \cdot 6 \times 10^{-7} \times 312 \cdot 5$, i.e. $2 \cdot 7 \times 10^{-4}$ coulomb. With particles of 10^{-4} cm. radius, the charge per particle would therefore be $0 \cdot 54 \times 10^{-14}$ coulomb, or $0 \cdot 54 \times 10^{-15}$ e.m.u., or 34,000 electrons. With particles of 10^{-5} cm. radius, the charge per particle would therefore be $0 \cdot 54 \times 10^{-16}$ coulomb, or $0 \cdot 54 \times 10^{-17}$ e.m.u., i.e. 340 electrons. Under the conditions imposed in the experiments with particles of, say, 4×10^{-3} cm. radius, i.e. movement in air at approximately 30 miles per hour, and an atmospheric humidity of less than 65, particles of 4×10^{-3} cm. radius, would carry 54,000,000 per particle; those of 10^{-4} cm. radius, 34,000 electrons; those of 10^{-5} cm. radius, 340 electrons. P. Beyersdorfer (133) using sugar dust, calculated that 1 gram whirled through a tube of 1 mm. bore gave a total charge of $8 \cdot 5 \times 10^4$ e.s.u. Since he calculated 420 electrons per particle, on the basis of the number of electrons touching the tube walls, the total charge

being $1 \cdot 9 \times 10^{14}$ electrons the particles must have been about $0 \cdot 45 \times 10^{12}$. If all particles passed through the tube were included, this would allow an average particle volume of about $2 \cdot 2 \times 10^{-12}$ c.c., and radius $0 \cdot 5 \times 10^{-4}$ cm. allowing unit density. The conditions under which Blacktin and Robinson find 34,000 electrons per particle, and Beyersdorfer finds 420 electrons per particle, differ considerably since the former used a tube of 127 mm. bore, and the latter a tube of 1 mm. bore. The figure of 4×10^{-3} cm. particle radius, moreover, is a maximum for particles passing a 200 I.M.M. sieve, so that the value of 34,000 electrons may be extreme. If the average radius could be taken as $0 \cdot 5 \times 10^{-4}$ cm. rather than 4×10^{-3} cm., this would give a charge of 540 to compare with 420 electrons per particle found by Beyersdorfer.

Possible Particle Populations at Different Heights.—Records of various workers give some idea of variation in particle number with height and locality. Whilst rare to find less than 100 particles per c.c., Swiss air has over 300 per c.c., and the figures in London may reach 10^5 or $1 \cdot 5 \times 10^5$ per c.c.—J. N. Friend (129)—and for various oceans and seas figures vary from 243 per c.c. for the Indian Ocean to 2×10^3 for the Atlantic. J. S. Owens (130) at Holme for four days in August 1921, gives an average of 227 per c.c., whilst finding in Madrid from 149 to $2 \cdot 5 \times 10^3$ per c.c., dependent on time of day; in a Sud express carriage, $1 \cdot 3 \times 10^4$ per c.c.; 180 per c.c. on Lake Toronto; 13,800 per c.c. at Hull; Spurn Head, 140 per c.c.; and London, 21,760, 39,000, 53,000 and 11,300 c.c., on various occasions in 1922—Shaw and Owens (130, 131)—and, in a dry haze 100 to 200 per c.c. The U.S. Department of Agriculture, Weather Bureau (172) using Owens' jet dust counter at American University found from 134 to 2,066 per c.c. from April, 1930, to March, 1931, and evolved the formula for local application:

$$V = 340 - 69 \log (RH + N)$$

where V is visibility in miles, RH is relative humidity, and N number of particles per c.c.; whilst H. H. Kimball (173) at the same university found from 176 to 2,328 per c.c. using the jet dust counter from April, 1931 to March, 1932. J. Aitken (28) found numbers varying from 400 c.c., on Ben Nevis, in August, to about 200,000 per c.c., in Paris in May, and in Java from 136,000 at 8 m. height, to 1,690 at heights greater

than 2,500 m., though G. Melander (132), Wigand (386) and others consider Aitken's method to count only hygroscopic nuclei—one factor in the dust population. Using an ultra-microscope, a bright, clear, sunny day in a city suburb might give 60,000 per c.c.

These figures show continuity of particle content all over the earth near its surface, though their characteristic be violent variation with locality and conditions. Aeroplane figures given by Shaw and Owens (130) give valuable information of particle variation with height. They vary from 67 per c.c. (average) at 5,000 ft., to 158 c.c., 52 c.c., and 1,357 c.c., at 6,000, 10,000 and 12,000 ft., respectively. Winds and eddy currents may prevent their non-suggestion of the Perrin distribution (17). They indicate a considerable particle population in the upper atmosphere, and since taken with the jet dust counter, which, it is suggested (page 173) may register but one particle complement, as the Aitken apparatus does another, and that the larger complement likely to be least numerous at high levels. J. Alexander (110) states that Stevens and Johnson, of U.S.A. Army reported at 39,000 ft., billions of visible ice particles, hanging in mid-air, and that test plates in an airplane show pollen grains to be numerous at 15,000 ft. If, say, 30,000 particles per c.c. of all the different kinds in the atmosphere could be taken for a height of 12,000 ft., and general particle size could be regarded as between 10^{-4} and 10^{-2} cm. radius, then meteorologically propelled at, say, 30 miles per hour charge per particle might vary from $3 \cdot 4 \times 10^{4}$ to $5 \cdot 4 \times 10^{7}$ electrons. Perhaps a particle average of 10^{-3} cm., and a charge of 100,000 electrons might be taken. The charge noted by Beyersdorfer (133) would give about 80,000 electrons per particle of 10^{-3} cm. making the necessary adjustment for reduction of total charge with that of total surface area. The spatial conditions of Blacktin and Robinson (126) more closely approximate, however, to those of the atmosphere. A natural spontaneous electrical charge of $(3 \times 10^{4}) \times 10^{5}$, i.e. 3×10^{9} electrons; $4 \cdot 8 \times 10^{-11}$ e.m.u., or $1 \cdot 44$ e.s.u., per c.c. would be provided. The particles, chiefly settling under Stokes' law, settle continually earthwards all over the earth, suffering digressions from their original course as carried by winds of varying velocities they continue to gather electrical charge, alternately with quiescent settling periods, and so forth. Large-scale evidence may be cited: "The prevailing wind in

the Persian Gulf and the Sea of Oman blows from the north-west and is called by Arabs 'shamal.' A shamal may occur in any month of the year, but it blows almost without cessation during June, and the early part of July, when it is known as the 'great' or 'forty-day shamal.' A shamal may set in suddenly at any hour of the day or night, and generally lasts from one to five days. Although the wind is not usually strong, rarely exceeding 30 miles an hour, it is very hot and dry, and carries great quantities of dust from the deserts of Persia and Mesopotamia. The sky is cloudless, but the haze is often so thick as to obscure the land, making navigation dangerous, and the decks of ships far out at sea are covered by a fine impalpable dust" (125). Whatever the mechanism of electrical charge generation (*cf.* page 225) much evidence goes to show that charge is divided as to one sign on the particles, as to the other, on the air through which they move. Adopting this explanation, there is a constant stream of charged particles falling on the earth with an equal and opposite charge in the atmosphere. The particles will transfer their charge to the earth. When winds, or other movements sweep them up again into the atmosphere they will be re-charged, and again falling, further re-charge the earth. This process will be continuous, the earth receiving a continuous charge from such falling particles. This earth-accumulating charge will balance that of opposite sign created in the atmosphere by the moving particles themselves, the earth and its atmosphere being like the charged plates of a condenser in this respect. This constant charge-generation will be indirectly due to whatever causes stock the atmosphere with the staubosphere.

Earth-charge Theories, and the Charge on the Staubosphere.—Whilst convection currents (in hot weather or regions) will cause a great rise of fine particles and increased electrical charging, volcanoes shoot fine dust through the troposphere into the stratosphere, giving it a great distance to settle. But the earth's own rotation and the resulting relative directions of the prevailing winds will in general be the chief function in circulating particles and causing electrification. The earth's charge due to particle deposition would, therefore, be ultimately largely due to the lag between the rotation of the earth and its atmosphere, fine dust particles being the activated, and active, agent. If particles have mostly like charges—unlike charges being located in the air, under mutual repulsion they

will settle as individuals, save so far as disintegration occurs from, say, " disruptive approach."

Various explanations have been advanced of the source of the earth's electrical charge, but according to W. F. G. Swann (135) " the source of replenishment constitutes the great mystery of atmospheric electricity." Since the flow of negative electricity to maintain the earth's charge is " against the field," the earth being already negatively-charged, explanations have been based on either (*a*) the operation of gravity, or (*b*) specially high velocity bestowed on negative corpuscles by some means. Thus C. T. R. Wilson, 1897–1900, regarded rain as the agency, whilst H. Ebert, 1904, advanced a modified previous theory of Elster and Geitel that negative charge was retained inside the earth, positive being dismissed and carried up by winds, etc. On the other hand, G. C. Simpson, 1904, suggested that of both positive and negative corpuscles shot out by the sun, only negative reached the earth, whilst W. F. G. Swann, 1917, and E. von Schweidler, 1918, suggested that the penetrating-radiation, in passing through the atmosphere, produced electrons travelling in the same direction, those coming within striking distance of the earth charging it. Rain replenishment is objected to on the grounds that its charge is 90% positive, and because of supply maintenance difficulty when formed only on atmospheric ions under very high supersaturation, and, in common with Ebert's theory, the variation in replenishment with barometric pressure. Objections to the corpuscular theories are the failure to observe any corpuscular charging of an insulated, exposed body, and the fact that ionization due to penetrating radiation should produce 60,000 ions per c.c. per second, whereas only about 6 are actually found. Simpson, 1916, and Swann, 1927, have also advanced a theory based on the death of positive charges within the earth.

Whilst evidence concerning the number of particles per unit atmosphere volume is rather meagre, and the difficulty of arriving at an electrical charge value, of corresponding magnitude, the earth-charge due to negatively-charged dust would be " against the field " and due to the action of gravity. Whilst barometric pressure variations would also affect degree of particle charging, the mass effect might be regarded as constant. Millikan observed that the frictional electrical charge developed on oil drops was always an integral multiple of electronic charge *e*.

A charge of $1 \cdot 44$ e.s.u. per cubic centimetre would provide a total replenishment charge of $7 \cdot 4 \times 10^{18}$ e.s.u. per second, the earth's surface being $5 \cdot 11 \times 10^{18}$ sq. cm., supposing average particle radius of 10^{-3} cm. which fall at $1 \cdot 2$ cm. per second in still air. The earth's charge being taken as about $3 \cdot 3 \times 10^{12}$ e.s.u., as suggested by L. A. Bauer (174) (taking average atomic weight of earth's substance as 50), adopting 30,000 per c.c. for the average atmospheric particle content, electrons per particle would require to average but 5×10^{-2} (i.e. 1 electron per 20 particles). Even supposing the figures previously quoted for differing heights were fully representative of particle content, their average would be 410 per c.c., requiring then rather under 4 electrons per particle. Or, adhering to the postulated average charge of 100,000 electrons per particle, a particle population of only 3 per 200 c.c. would be necessary. Allowing, therefore, for eventualities such as (1) variation in particle size; (2) variation in particle number per c.c.; (3) constant variation in charge on individual particles due to velocity changes, and distribution variation due to wind variation, and (4) neutralisation of opposite charges before reaching the earth's surface, the possible particle electrification on the above basis is more than amply sufficient to supply the earth's charge.

The kinetic energy of a particle of 10^{-3} cm. radius of density, say, $2 \cdot 5$, moving at 1 cm. per second, is approximately $0 \cdot 5 \times 10^{-8}$ erg. From the invaluable "Interconversion Factors for Energy Expressed in Different Ways," of C. H. Douglas Clark (412), $0 \cdot 5 \times 10^{-8}$ erg equals $1 \cdot 26 \times 10^{4}$ electron volts. Were the energy of motion completely transformed to electrical charge, such a particle would therefore gather 12,560 electrons at 1 volt. At a velocity of, say, 30 miles per hour, its kinetic energy being $0 \cdot 88 \times 10^{-2}$ erg would represent, under the above equality, $7 \cdot 14 \times 10^{9}$ electron volts. Allowing for the transformation of kinetic energy into other than electrical to the unlikely extent of even $92 \cdot 75\%$, the electrical energy would still be sufficient to provide per particle of 10^{-3} cm. radius, 100,000 electrons at 4,000 volts, as previously derived from actual electrification measurements. The great dust storm, originating in Canada, probably covering $1{,}500 \times 900$ miles, 3 miles deep, enveloping New York with grey dust on May 11th, 1934, had an estimated speed (by air pilots) of 60 to 100 miles per hour (540). Great damage has been caused by this record American storm.

CHAPTER IV

DUST IN NATURE—CONCLUDED

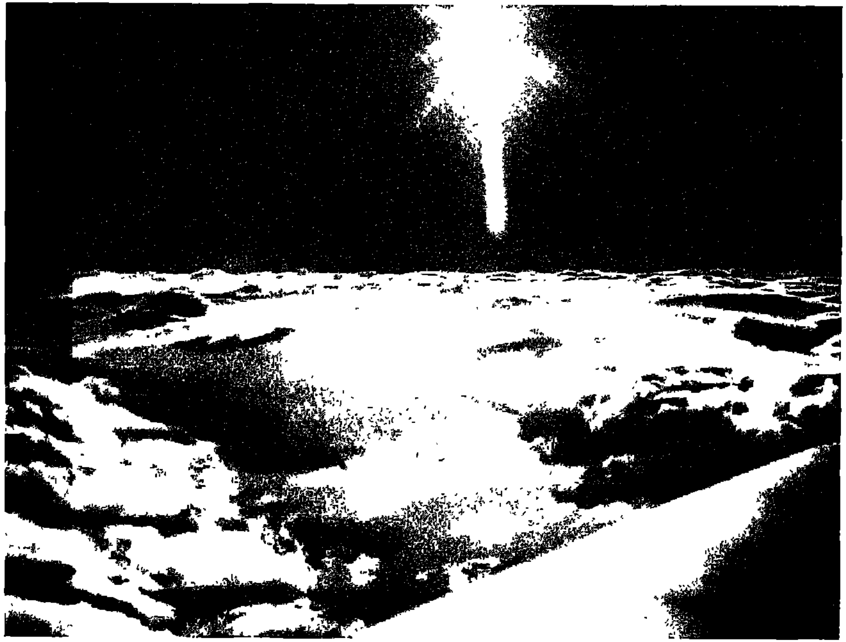
THE METEOROLOGICAL CONTROL OF THE STAUBOSPHERE.

The Distinction between Visible and Invisible Particles.—A diameter of 50 micron may be regarded as the dividing line between visible and invisible staubospheric units, and approximate sizes of various individual components may be given as :

TABLE I

Nature of Particle.	*Particle Size.*
Smallest (Cunningham) zone	Less then $2u$ dia.
Medium (Stokes) zone	200 to $2u$ dia.
Largest (gravit.) zone	$200u$ dia. up.
Smoke particles	$0{\cdot}5u$ dia.
Cloud particles	6 to $18u$ dia.
Sandstone particles	$5u$ up.
Spores, moulds, etc.	$30u$ down.
Pollens	$25u$ up dia.
Bacteria	$1u$ dia.
Fog particles	15 to $35u$ dia.
Clay particles	$5u$ down.

The (1) vast spore, bacterial and pollen content ; (2) innumerable smoke particles of all kinds, and (3) that staubosphere zone, in general, which does not settle, and therefore grows, are all invisible. Cloud and fog particles less than 50 micron diameter, and liquid, each have an original solid nucleus (not formed on ions) itself invisible, and probably relatively small even in the invisible region. The only important visible particles, therefore, are the largest zone members, which rapidly cease circulating ; some members of the medium zone which slowly cease circulating ; special particles comprised in colloid systems (e.g. smoke agglomerates) or carrying wings or plumes (some seeds). The largest zone members may be regarded as dust up to 8 mm. diameter (*cf.* Dust in Geology).



[By courtesy of the "Daily Herald."

FIG. 2.—ABOVE THE CLOUDS. A STRIKING ATMOSPHERIC DUST EFFECT.

Sun-pillar due to light refraction by ice particles. Most of the particles must have been less than one thirty-thousandth inch diameter.

[To face p. 40.

This will include almost all loam, clay, earth, sand and gravel (whose upper limit is 2 cm. diameter) in Atterberg's mineral size classification, which gives clay as 2 micron downwards.

What is generally and empirically regarded as "dust" because visible, comprises the least numerous, the least important, the most transitory section of the staubosphere. Whilst supposed non-existent (invisible) units are the most abiding, most numerous, most important component, pregnant with continuous serious significance. Obvious road-dust clouds are examples of the former, whilst the latter, when numerous make the air hazy or "thick" without revealing their individual presence. If haze is absent, or almost so, then the fine particles are giving no sign of their presence, whilst the finest-zone particles probably give no hint even when present in large number. Even a smoke particle is only a hundred times the size of a starch molecule (5 millimicrons). The higher atmosphere contains numerous finest-zone particles which have circulated there for an unassessable period, and will be verging towards the size order of molecules.

Quantitative Wind Movement of Dust Particles.—Variation of pressure with wind velocity is shown in the following table, due (except first column) to A. Geikie (158):

TABLE II

Pressure. Gram. per sq. cm.	*Lbs. per sq. ft.*	*Velocity. Miles per hour.*	*Condition of wind.*
—	—	—	Calm.
0·5	1	14	Light breeze.
4·5	9	42	Strong breeze.
12·5	25	70	Strong gale.
18·0	36	84	Hurricane.

When the wind force is just strong enough to move a dust particle along the ground without friction, i.e. ideally, at 1 cm. per second,

$$\text{force expended} = \text{kinetic energy} = \tfrac{1}{2}\, m\, v^2$$

where m is mass of particle, and v is particle velocity.

For a velocity of 1 cm. per second—adopted as lowest movement limit giving least friction—the wind force acting on the hemispherical surface of a spherical particle will be $\tfrac{1}{2}m$. For

a "light breeze" pressure 0·5 gram sq. cm., the particle radius at which the particle will just commence to be moved will be given by:

$$\tfrac{1}{2}m = 0{\cdot}5 \text{ gram sq. cm.}$$

$$\text{i.e., } \tfrac{1}{2}\,(4/3\ \pi\ r^3\ d) = \frac{4\ \pi\ r^2}{4} = 0{\cdot}62 \text{ cm.} = r$$

if density d is taken as 2·5 as for quartz particles, and wind pressure all regarded as applied to particle hemisphere.

For particles of 10^{-1} cm. radius, the pressure 0·5 gm. sq. cm. of a light breeze would be 6·28 × the optimum value to commence moving the particle at 1 cm. per second. For particles of still less radii, the excess force varies inversely as the particle radius. This will apply to winds of all pressures and speeds, and the optimum particle radii for winds of velocity 42, 70, and 84 miles per hour are respectively 5·46, 15·2 and 21·9 cm., density being taken as 2·5. Of many materials of less density, the radii would be correspondingly greater, or vice versa.

With any wind, the excess pressure over that required to move a given particle at 1 cm. per second would be exerted in overcoming gravity and increasing the velocity. As v^2 is involved, the increased velocity would be as the square of the excess pressure, which for a given particle would increase with wind velocity as the square of increasing particle velocity. This means there would be a relative deterioration of particle-movement speed increase, with increasing wind velocity. For particles belonging to the finest-zone, less than 10^{-4} cm. radius, the pressure of a light breeze (14 m.p.h.) would be $6{\cdot}28 \times 10^3$ times that necessary to remove those of largest size, viz. 10^{-4} cm. radius at 1 cm. per second and density 2·5. For still smaller ones, 10^{-5} cm. radius, it would be $6{\cdot}28 \times 10^4$ times in excess, and so forth. Were this surplus pressure all applied in increasing the velocity of a particle 10^{-5} cm. radius, this would only rise to about $2{\cdot}5 \times 10^2$ cm. per second, the wind velocity (14 m.p.h.) being about $6{\cdot}3 \times 10^2$ cm. per second. But, in fact, much surplus pressure would be used in work against gravity, and in overcoming friction either static or kinetic. According to Amonton's law—1699—confirmed by Euler, Coulomb—1781—and Morin—1830—energy used in friction should always be one-third the total pressure, Morin finding static friction usually greater than kinetic. And though this proportion may be greatly exceeded for clean surfaces, it can

be regarded as applicable to the contaminated surfaces of most particles in nature, though varying with contamination. Excess wind pressure of a light breeze being so greatly in excess of that necessary to move such a particle of 10^{-5} cm. radius, and—as seen in the last table—the wind pressure increasing as the square of the wind velocity, an inappreciable zephyr of 3·5 miles per hour, would have a pressure excess of about 4×10^3 over that necessary to stir such particles. Considering the numerous air currents of at least equal pressure in the atmosphere; the exceedingly slow settling speed of such particles in still air (viz. 60 years from a height of 6 km.); their deceleration and mobility; it is obvious that few, if any, can ever reach the earth, even though some extra energy would be required to lift them, as distinct from merely moving them. And since the particles of the medium (Stokes') zone have a maximum radius of 10^{-2} cm., excess pressure of 62·8 times that necessary would accrue for them in a light breeze of 14 m.p.h., reduced to an excess of about 4 in a zephyr of 3·5 m.p.h., whilst a breath of air of 1·75 m.p.h. would just move them. As the visible staubosphere has a minimum size of about $0{\cdot}25 \times 10^{-2}$ cm. radius, such a breath of air would be sufficient to move them and endow them with a velocity of over 1 cm. per second. This explains the ease and frequency with which light breezes will raise large clouds of visible road dust. Those numerous particles of the medium-zone which settle will, therefore, given a convenient situation for wind access, have small chance to remain settled. But as they will constantly tend to settle, the question arises of the heights at which vertical, rising, wind or convection currents will arrest the continuing particle fall. Such variations will, of course, arise as a result of climatic difference. C. W. Thornthwaite (175), in regard to (1) precipitation effectiveness, and (2) temperature efficiency, suggests necessary modification of the Köppen classification based on vegetation, giving 120 possible different climatic types, and 32 practical climatic types. Since (1) and (2) are themselves dependent on dust content, and their resultant climatic effect will determine dust distribution, it becomes obvious that climatic type and staubospheric content of any given region are interdependent. This important conclusion shows that dust determines weather, and weather, dust distribution. Practical instances which seem to support it are put forward by J. R. Ashworth (522)

concerning flying observations of Colonel, the Master of Sempill, who on two occasions, (*a*) over the Welsh hills west of Birmingham, whose smoke reduced visibility in a N.E. wind, and (*b*) over South Cornwall with a N.E. wind, experienced rain accompanying excessive atmospheric pollution, the aeroplane being " absolutely filthy " on the first occasion, and covered with soot on the second. Also, according to J. Alexander (110) W. D. Bancroft and L. F. Warren showed that electrified sand scattered from an airplane would cause slight local rain.

The terminal velocity of medium-zone particles in still air will actually be constantly varied by convection currents and winds. Since convection currents lose velocity with height (eventually forming " decks " of still air), medium particle velocity will be the terminal one for the local air density at deck level, gradually decreasing as the particles fall meeting more quickly-rising air. And, in a steady vertical breeze of unvarying velocity, the extent to which their normal terminal velocity will be reduced will depend on the angle of the axis of the wind to the vertical, and the corresponding vertical complement of the wind pressure. Obviously, also, the height at which the vertical pressure of a wind of unvarying pressure totally balances the particle pressure, thus arresting its fall, will depend on the angle of the wind axis to the vertical. Hence, this balance point is the starting point at which the particle will cease falling under its governing law and be propelled by wind pressure in wind direction. The wind gradient (wind velocity being constant) is likely to have a large effect in determining at what level in the atmosphere particles shall be swept up from their normal course. Again, the excess pressure of the wind over that of a given particle will be increased with increase of the angle between wind axis and the normal, as the gravitational pull on the particle will be diminished with respect to wind direction. The nearer the wind to horizontal, therefore, the greater can become the maximum speed of a particle of given size in a wind of given pressure.

Particles will, therefore, travel greatest distance in unit time in a horizontal wind (excluding the consideration of descending wind currents). Also, the more vertical the wind, the less the height at which it will sweep into its movement particles of a given radius, but the less the distance it will carry them.

Wind Systems which chiefly control Dust Movement.—Such

wind systems will principally include geostrophic winds of value v in the equation:

$$bb = 2\, w\, v\, d\ \sin L$$

where d is density of moving air; L the latitude; v the velocity of a mass of air moving freely with reference to the earth along a great circle without change of velocity; bb the gradient of pressure; and w the rotation of the earth: gradient winds, which are geostrophic winds applied along a small circle of the earth of angular radius r lying in a horizontal or level surface: and cyclostrophic winds which refer to those of very small latitude—W. Napier Shaw (145).

Dust Distribution by Chief Wind Movements.—The principal world-wind systems will be paths of constant dust flow. Commencing hot and gradually cooling from equator polewards, northern hemisphere winds will gradually lose height as they approach high-pressure-calm regions. The fine-zone and medium-zone dust particles will be chiefly gathered, which together may be called stratospheric dusts. Returning equatorwards nearer the earth, such winds will now gather the medium-zone and large-zone dusts—terranean dusts—to substitute the stratospheric complement. A similar, geographically-reversed movement will occur in the southern hemisphere.

Of these immense horizontal particle streams, the lower heading equatorwards, the higher poleswards, the latter are likely to possess smaller average particle size, and steadier stronger wind movement. Greater maximum particle speed and travel in unit time due to these causes, apart from reduced atmospheric resistance, will occur in the stratospheric than the terranean stream. And the latter tending to move nearer the earth diurnally will carry a still-slower complement of earth-raised dusts then than at night. Subsidiary, more or less vertical streams are likely to constantly supplement either the higher or lower main stream.

A general mixing of the various classes of dusts whether terranean or stratospheric, deposited or circulating, and of all three size-zones will tend to result. New meteoric dusts will probably be caused lateral transposition by these wind streams, or swept up into the upper stream, instead of settling vertically. This effect will be superposed whether finest-zoned they tend to have horizontal mobility, or medium-zoned to have vertical mobility. The main streams will be a barrier to the rising of

deposited dusts (save those which they carry) to the highest regions, thus—outside their own mixing effect—tending to prevent mixing of terranean and stratospheric dusts. In the two hemispheres (ignoring the effects of secondary wind systems) the general stream-mixing will result, respectively, in different dust products. For, if the stratospheric complements can be regarded as similar throughout, the terranean complements as distinctly vary, creating comprehensive variation throughout the streams. Thus, in the northern hemisphere modern commercial industrial iron and coal dusts will predominate. In the southern natural deposit dusts supplemented by those from ancient, non-industrialized, civilizations.

Dust Distribution by Subsidiary Wind Movements.—The chief wind-streams meet and create narrow regions of calms and tornadoes or equatorial doldrums. Changing position with the seasons they are irregular and spasmodic in force, varying in pressure distribution dependent on whether they are north or south of the equator. Monsoons belong to this system, whilst full particulars are given by W. N. Shaw (145) regarding pressure distribution and flow direction, etc.

It is plain that the dust populations, respectively carried by the hemispherical complements will be blended in these secondary wind regions. This implies that in the doldrums—the calm, windless regions—the mixed resultant dusts will be given every opportunity to settle vertically, or disperse horizontally according to their particle size, modified to the extent to which it is claimed for raindrop nuclei. In tornado regions they will circulate still more violently unless deposited as rain nuclei, their normal quiescent particle distribution being destroyed by the violent conditions. In general, where continuing to circulate their movement will be relatively circumscribed as compared with their chief-stream movement. Their mixing, consequently, will be more thorough. Where not rain-deposited therefore, the dust population of secondary systems will be more heterogeneous, whilst a cross-section would be more homogeneous. From monsoon winds a tremendous particle population over a long-continued period—continuously supplied by chief-stream wind systems—will be rain-precipitated on earth or in sea, although these supersaturated conditions may also be best for ions as nuclei.

High electrical condition is a further doldrum characteristic.

The meeting of southern and northern chief dust streams may cause this. Their intense dust variation is explained and confirmed by W. N. Shaw's statement (145) the doldrums are " at the line of junction of the air of the two hemispheres with completely different life histories. There is no reason to suppose that their condition is the same in respect of any of the meteorological elements except pressure. Temperature, humidity, electrical condition may all be different." The mixing of the highly-differing industrial and non-industrial complements, in view of the chemical view of electric charge generation, may well produce this high electrical tension. Or if charge depends primarily on contact between particles and air molecules, possible increased particle population or greatly increased movement and collision probability due to stream opposition, may explain the high tension.

The Westerlies.—These are likely to have large local effects, though setting polewards from 30 to 50 degrees north and south latitudes, they are likely to add but incidental dust amounts to chief-stream circulation. For what they carry polewards will not be greatly augmented from cold, sparsely inhabited regions. They are regions of cyclones and anticyclones with corresponding subsidiary dust movements. Thus, in favourable winds, alternating warmer and cooler air blocks, e.g. where cumulus clouds with a rising air column underneath have an average joint-density less than that of surrounding air—F. J. W. Whipple (142)—may produce a layering and echelon arrangement of dust due to varying height of similar-sized particles otherwise confinable to the same general cross-section. Prevailing in the northern Atlantic and stretching south polewards they have, however, important local dust aspects. Modern industrial dusts allied to the prevalence of westerlies in some industrial countries has decided sociological population distribution in numerous cities. There is also a large geographical effect due to such industrial dust-laden winds passing over widespread European tracts, which were and still are, the production centres of such dusts. They tend to carry these metallic and carbonaceous domestic dust populations in definite directions over the globe. Instrumental, in the northern hemisphere in moving warm, Gulf-stream waters to north-western European shores, thus greatly humanizing these regions, they at once convey for incidence on the consequent much greater population, a con-

tinuous and ever-increasing output of modern industrial dusts.

The prevailing west wind in England is its scavenger of the industrial dust output, an effect enhanced by the great anti-cyclonic activity of such winds. Such dusts will mingle with all other kinds whilst travelling and with those of other systems where they meet. Over industrial Britain, the clean winds which have traversed the wide Atlantic, south-westerly in summer or north-westerly in winter, will have maximum capacity for industrial-dust absorption and transference to north-western European regions such as Scandinavia. Its ready occurrence is gathered from the carrying of fine Icelandic volcanic dusts across Scandinavia to the Swedish east coast in 1874 and 1875. Similarly eastern British districts will have a more dust-contaminated atmosphere, to which to add their own instalment, or from which to receive the western, cleaner-aired, contribution. Thus, irrespective of their own productions, Ashington (Northumberland) and Leicester, might readily modify their respective classification (147) regarding dust, if geographical transmutation were possible. Since 5 micron diameter particles or less will travel 276 miles in a 10 m.p.h. wind starting at a height of 300 ft. (146), and those of 1 micron diameter over 8,000 miles, whilst the British Isles will only receive over the Atlantic the finest American dusts, north European countries will receive these, and additionally, a much greater particle-range of British industrial dusts, for varying conditions will probably often cause the much easier spanning of the 300 to 400 miles than would occur with a 10 m.p.h. wind and a starting height of 300 ft. Such countries will, therefore, to that extent, have an atmosphere of less dust-absorbing capacity than the British. The west-European coast line is therefore likely to have dirtier air than the west-British coast line. This will be counteracted by rainfall cleansing and nucleization, and inland, much more so, by hydro-electric rather than fuel-consumed power production in the Scandinavian countries, probably producing, on balance, a cleaner general atmosphere than in Britain. There will probably be a gradually-increasing metallic and carbonaceous dust deposition from south-western to north-eastern Europe, with a break in continuity over the North Sea where only vessels add a dust complement.

The southern hemisphere westerlies region will be both relatively free from land-formed dust, and almost completely

free from industrial dust, precipitation being largely dependent on salt particles. Speaking generally, and regarded chemically —there will be variation due to volcanic, cosmic and added circulating dusts—southern region rainfall will be due chiefly to inorganic dust nuclei, northern to carbonaceous and metallic dust nuclei.

Polar Dust Circulation.—Arctic and Antarctic air circulation may be chiefly self-contained and circulatory, the former about twice the area of the latter. Dust not of cosmic origin will be dependent for existence on low temperature. Precipitation will be small owing to rarity of convection currents, and small water vapour percentage, and will be as snow, remaining as such save where regelation-converted to ice, or vaporized or melted—slow processes. Snow and fine ice spicules will be the chief dusts, the summer snow limit being near the Arctic circle whilst rain probably never falls—even in summer—in the Antarctic circle.

Temperature will preclude hygroscopic nuclei, and if snow—like rain—requires nuclei for formation, it is difficult to see how precipitation could occur save by formation of snowflakes on snow particles or cosmic dust, as rain, at high supersaturation, may form on liquid particles. The air is often filled with fine ice needles even in clear weather which, after settling, are lifted together with fine snow by wind, impairing visibility, and possibly exposing the ground to denudation by wind and frost. Winter fogs also are substituted by fine snow particles which similarly darken the air.

In the stratosphere, temperature over the equator is low, over the poles, high. Owing to the tendency of fine dusts to be repelled in the direction of falling temperature gradient, a horizontal " convection " effect may be produced counteracting the polewards flow of fine stratospheric dusts. The general effect may be to force down such dusts in temperate latitudes (i.e. to reduce the scope and reach of the chief-stream circulation) thus preserving the isolation of the poles.

Trade Wind Characteristics.—Blowing steadily from about 30 degrees latitude in both hemispheres equatorwards, they may be classed with the terranean complement of the chief-stream circulation. Their point of origin as regards dust content is the high atmosphere or stratosphere over the low-pressure equatorial calms where the heaviest rainfall has cleansed them from particulate matter acting as nuclei.

Gradually losing height in travelling north and south polewards as anti-Trades and becoming more and more charged with surplus particles from less-rainfall regions in higher latitudes, they are forced down at the high-pressure calms, 30 degrees latitude, neighbourhood with their dust load. Returning equatorwards at low altitudes—Trade winds roughly following continental coasts—they will gather more dusts of the medium and larger zones. To some extent they will be fed by dusts from the Westerlies though these chiefly blow polewards. Since for rain formation on ions, as distinct from particles, very high supersaturation is needed, this form of precipitation is likely to chiefly occur in tropical regions. It is probably a supplementary way in which deficiency of staubospheric particles in the tropics is made good to maintain the heavy rainfall.

Katabatic Wind Dust.—Cold gravitational winds which flow down mountain sides into valleys, they often attain great strength. It is to be expected that they will have a similar—but much more temporary—dust content to Arctic and Antarctic winds, being well-charged with snow and ice dust. But additionally, they will also carry dusts of other classes, dependent on the respective condition and position of the mountain or mountains with regard to neighbouring controlling features and their position with regard to the wind systems. The loss of up to 2,000 ft. altitude in a few seconds by aeroplanes of the Houston Mount-Everest expedition flying close to Mount Everest, was probably a Katabatic wind effect.

Some idea of the dust-content of terranean winds is suggested by Carveth Read (140) which he attributes to Bain (141) in the following quotation: "The north-east wind is generally detested in this country; as long as it blows few people feel at their best. Occasional well-known causes of a wind being injurious are violence, excessive heat or cold, excessive dryness or moisture, electrical condition, the being laden with dust or exhalations. Let the hypothesis be that the last is the cause of the north-east wind's unwholesome quality; since we know it is a ground current setting from the pole toward the equator and bent westward by the rotation of the earth; so that, reaching us over thousands of miles of land, it may well be fraught with dust, effluvia and microbes. Now, examining many cases of north-east wind, we find that this is the only circumstance in which all the instances agree; for it is some-

times cold, sometimes hot; generally dry, but sometimes wet; sometimes light, sometimes violent, and of all electrical conditions. Each of the other circumstances then, can be omitted without the north-east wind ceasing to be noxious; but one circumstance is never absent, namely, that it is a ground current. That circumstance, therefore, is probably the cause of its injuriousness."

Particle Settlement and Wind Pressure.—The force exerted by a falling particle being mg, this will be $\frac{mg}{0{\cdot}5m}$, i.e. $2g$ or $1{\cdot}96 \times 10^3$ times the force required to give the same-sized particle of the same density a kinetic energy of $\frac{1}{2}m$ (at a velocity of 1 cm. per second). Hence, a smallest zone particle of 10^{-4} cm. radius (whose moving force from rest will be excessed by $6{\cdot}28 \times 10^3$ in a light breeze of 14 m.p.h.) will be only excessed by $3{\cdot}27$. At whatever height, therefore, a vertical rising wind of 14 m.p.h. loses pressure until it becomes $3{\cdot}27^{-1}$ its original value, particles of 10^{-4} radius which it has been carrying up, will commence re-settling. Again, a wind of initial pressure $3{\cdot}27^{-1}$ of 14 m.p.h., i.e. $7{\cdot}7$ m.p.h., velocity will be just sufficient to prevent such particles settling no matter at what height they are encountered. Similarly in convection currents when, with increasing height, the pressure has fallen to $0{\cdot}153$ gm. sq. cm. (assuming it originally greater than that) particles of 10^{-4} cm. radius will cease to be moved by it. Whilst for particles of 10^{-5} cm. radius, the excess pressure of a 14 m.p.h., wind will be $32{\cdot}7$ times that necessary, with a minimum wind velocity or convection current of about $2{\cdot}5$ m.p.h. to balance the falling particle, the upper particle radius just balanced by a 14 m.p.h., current will be $0{\cdot}32 \times 10^{-3}$ cm.

It is, therefore, obvious that a large proportion of medium-zone particles will not be stopped even by a vertical upward breeze of 14 m.p.h., and 10^{-2} cm. particles will require a wind of about 80 m.p.h., i.e. a hurricane. Particles of 10^{-2} cm., will, therefore, settle through practically all winds, producing a steady " rain " on the earth. This limit for the above reasoning, falls congruent with the upper limit of 10^{-2} cm. radius generally recognized for Stokes' law operation.

Winds and convection currents will, therefore, give a gradation or layering within the settling Stokes' law particle zone, according to size.

If rising air currents, convection or wind, get feebler with height, the general result will be that vertical rising currents will keep finest-zone particles at a generally higher level than medium-zone particles. Such effect will be superimposed on the normal still air Perrin effect (17) of denser layers at lower levels, and the mass effect will probably be for medium-zone particles to accumulate at lower levels, and finest-zone at a higher level, giving a layer of finest particles high above a layer of larger ones, all, however, being less than 10^{-2} cm. radius. Winds and air currents by disturbing all others, will probably make evident an upper non-settling layer of finest particles. They will churn up the normal Perrin atmospheric distribution. Ehrenberg's (176) microscopic examination of wind-born desert dust caused him to suppose the existence of air-swimming dust-cloud circulated and controlled by the Trade and anti-Trade winds, because such dust contained numerous S. American diatom species.

The lower and upper layers will mutually permeate and pass through each other, and their units will constantly collide. But since the strongest vertical winds will but retard, not arrest particles between say 10^{-3} and 10^{-2} cm. radius, whilst driving with them those less than 10^{-4} cm. radius, whenever there is a vertical wind or convection current over 7·7 m.p.h., finest-zone particles will tend to be driven through (i.e. between) medium-zone particles, to move relatively faster than the latter in opposite direction. At less than 7·7 m.p.h., wind or current medium-zone particles will have relatively larger velocity, and relative movement direction will be reversed, medium-zone moving through finest-zone. Thus, there will be constant attrition over long periods responding to the to-and-fro shuffle, varying with relative direction between finest-zone and medium-zone particles, eventually culminating in full settlement of the medium-zone particles (since winds over 80 m.p.h. may be rare) and height retention of finest-zone particles. Some actual experimental confirmation of such effects seems provided by the aeroplane determinations of H. H. Kimball and I. F. Hand (177) and C. le Roy Meisinger, when particle numbers were recorded at 2, 4, 6, 8 and 10 × (10^3) feet height, respectively, and even up to $1·4 \times 10^4$ feet. With a clear sky, in the morning more dust was found near the ground, and less between 2×10^3 and 7×10^3 feet, but later in the day there was a high-level increase. Often with clear skies the

dust content increased with height up to about 2×10^3 or 5×10^3 feet. Though convection would not carry-up medium-zone particles, the increasing accumulation at considerable heights must have been due to the deceleration of such particles by the upward current pressure, possibly plus the actual lifting of some rather low finest-zone particles. J. Aitken (28) noticed on Rigi Kulm in some weather a morning minimum and hottest-part day maximum of air particle-content, considered due to convection currents from valleys or ascending wind. This was confirmed on Ben Nevis by A. Rankin, who also found a yearly maximum in March, April and May, such being considered due to more frequent south-east winds bringing impure air from densely-inhabited parts.

Particles, never likely to reach the propellant-wind velocity, not moving integrally therewith, must be regarded as retaining their individuality. Colliding, with impact dependent on their kinetic energies, rather than sliding round each other. Such impacts largely provided by the to-and-fro shuffle, will give great electrical charging opportunity. Such charges will be separated by the layering effect, that of one sign falling with medium-zone particles, the other retained with high finest-zone particles. The fact that raindrops are sometimes positively, sometimes negatively, charged, may be due either to the different charge sign of the original nuclei, or to the balance of signs amongst the particles collected (soluble or insoluble) in falling.

Horizontal and Vertical Particle Division.—Horizontal winds will be resisted only by the horizontal complement of the gravitational pull on particles. Therefore, such winds of much less than 80 m.p.h. will carry particles of 10^{-2} cm. radius with them, and, of course, all smaller ones. But such larger particles will continue settling under gravity whilst drifting, until, at 80 m.p.h. they will be fully drifted and cease settling. They will wholly drift, settle, drift again, etc., alternatively with pressure, the overall tendency being drifting whilst settling. Horizontal to-and-fro shuffling dependent on particle-size variation and due to change of wind direction, will be relatively localized since the chief winds are prevailing ones. The finest-zone particles will always be carried through the medium-zone, never vice versa as in the vertical effect. Electrification will result.

Except when wind velocity is over 80 m.p.h. there will,

therefore, be two main particle streams, finest-zone being propelled equatorwards, medium-zone settling earthwards with drift. Proportions of particles racing horizontally; partially drifting and settling; or totally settling at any time or place, will be determined by direction, force and persistence of controlling winds, conveying particles, whilst not destroying particle individuality.

The mass effect of all wind pressures on the invisible, innumerable, staubosphere units, will be division into horizontally and vertically-moving complements, the latter being larger and selectively forming a lower layer; the former smaller and forming a higher layer. Ehrenhaft (99) has shown that when particles are greater in diameter than the dispersion medium mean free path—say 1×10^{-5} cm.—their gravitational velocity exceeding their velocity due to molecular impacts, the particles fall in a zig-zag line, but with smaller particles down to 1×10^{-7} cm. diameter, the molecular impact effect is greater than the gravitational. This will tend to produce horizontal and vertical particle complements applied atmospherically, even without considering wind effects.

The General Effects of Wind Particle-Movement.—Wind movement equatorwards through the lower layer will transport all the finer particles and drift some of the less-fine, to the low-pressure calms. Here convection currents will sweep up the finer particles, allowing the less fine to settle at modified terminal velocity decided by convection-current and wind velocity. Some will form raindrop nuclei. The finest particles driven highest will, in high cooler, slower, air currents form raindrop nuclei. Many will be precipitated, all having been driven through the less fine particle zone. Those less than, say 10^{-4} cm. radius will have now reached their natural region where, propelled by steady high-speed winds to the high-pressure calms, after being forced down, they will be again circulated in the natural wind cycle, though some will be carried up by a short route to their natural layer by local breezes of all pressure variations. Previous figures are based on a particle density of 2·5, since volcanic, meteoric and earth-formed dusts are mostly of high density. Low density dusts, e.g. plant spores, will have modified behaviour, due to slower settling and easier propulsion. "Particles" such as smoke agglomerates, really small colloid systems, will belong to this class on account of low density, whilst size classes them

in the accelerated large-zone outside the permanent staubosphere.

The persistency of world-wind circulation which controls staubospheric movement is shown by Brooks and Hunt (178) who state that since 1341—regular observations having been made since 1667 in London—the wind in the British Isles has been almost wholly from west-south-west, and in the present century from south-west. Winds over deserts and tropical seas may also be persistent, with high velocities, though over the latter suffering more fluctuation than at the Poles, and cities cause frictional air churning—C. S. Durst (179).

Unlike other atmospheric constituents water vapour is not mixed and diffused by winds, but remains practically constant for different latitudes. Since most raindrop formation will occur on solid nuclei, greater or less than 10^{-4} cm. radius, a vaster staubosphere will be always required in tropical regions for rain formation, than in more temperate ones. Though tropical and semi-tropical regions are those where vast natural spaces lend themselves to dust formation and where erosion is probably most effective, temperate regions have their huge, specialized industrial dust production. Thus, general over-supply of particles than tropical rainfall necessity being supposed, temperate regions will always have a greater particle residue than tropical. If, otherwise, the tropical air dust content is not sufficient for its own rainfall, the world-wind systems will, as outlined, probably supply the deficiency from higher-latitude surplus. As there is some evidence that excess dust itself propagates rainfall, the latter dust-insufficiency alternative may be the true effect. Thus J. R. Ashworth (143) comparing industrial area Sunday rainfall during periods of (*a*) increased Sunday smoke output (during Great War), and (*b*) normal Sunday smoke output, found in (*a*) Sunday rainfall much higher, in (*b*) much lower, and less than weekday rainfall. This may mean that, normally, in absence of sufficient smoke, nuclei are insufficient to precipitate the available moisture. Ashworth (144) also found most ultra-violet light on Sundays and least on Wednesdays, perhaps not due to pollution for the above reasons—using a method of integral estimation of radiation devised by L. Hill who himself found least ultra-violet light in the British Isles in central London.

Dust, Rain, and Lightning.—Save in cold weather, when it

is negligible, atmospheric water-vapour content is generally over 1·2% by volume, and may be as high as 5%. Hann has shown the value at the equator to be 2·63%; in latitude 50 N., 0·92%; and in latitude 70 N., 0·22%. The thunder-cloud-formation theory of G. C. Simpson (60) and Humphreys (60) that electric charge is created by air-current splitting of larger drops into a spray of smaller ones seems to imply a considerable velocity of such air currents. They will be carrying dust particles whose previous charge will probably be largely transferred to the split water drops, more likely to be more dust-charged than normal raindrops. If 100 c.c. of air were required to form 100 small drops from a large one, and all charge (of amount previously postulated) were transferred, each small drop would carry 9×10^8 electrons or 0·43 e.s.u. About 8×10^7 drops would be thus required to provide 1 coulomb of electricity. Since the theory allows for many successive coalescences and drop re-splittings, dust-charged air might readily promote the average figure for lightning flashes. Normal staubospheric dust will be present in all thunderstorms, whilst its particular presence is suggested by F. Chapman (136), who, discussing the origin or Tektites or Australites, states: "We may readily conceive how whirling dust in cyclonic storms such as are known to take place in Australia might be fused by the discharge of the lightning which often accompanies these electric storms," as also by the counter-suggestion of L. J. Spencer (136) that "no tektites (aerial fulgurites) have been picked up after the discharge of lightning through dust storms." A. Geikie (138) regards fulgurites as being formed by the action of lightning on loose sand and soil particles. The summit of Little Ararat is completely drilled with fulgurites owing to the numerous thunderstorms. But L. J. Spencer (139) considers them to be formed by terrestrial contact of feldspar, etc., with incandescent meteors.

The Depth of the Staubosphere.—The atmosphere's height not being known with certainty, the depth of dust persistence cannot be stated. It may have no determinable upper limit. If the two are regarded as coextensive, then auroral displays may occur at 500 km.; meteoric observations suggest 150 to 300 km., and twilight duration probably 64 km. But whatever the total depth, Halley's law shows that half the air is below 6 km. A recognized figure for the troposphere (the

normal atmosphere) divided by the tropopause from the stratosphere is 10 km. Clouds formed above the troposphere in the tropics suggest the presence of dust particles above 10 km. there, whilst volcanic dust permeates the stratosphere, which extends to 60 km., beyond which—at 150 km.—Lindemann and Dobson suppose meteors are luminous. Meteoric, dust, therefore, if no other, must be found at 150 km. Since the Kennelly-Heaviside ionized gas layer varies from 40–50 km. to 90 km. from day to night, meteoric dust must pass through it. Such dust, if playing no part in the night ionization (day ionization is caused by the sun), must be affected thereby. It has been shown that with increasing height the finest particles become more mobile and that they have a deceleration from earth. Finer meteoric particles, therefore, formed at 150 km., are at least as likely to move still higher as earthwards, perhaps reaching or surpassing 3,300 km., where there may be but 3×10^5 molecules per c.c. At these great heights, where " height " has lost its meaning, the medium molecular mean free path will probably be great enough to cause even particles of 10^{-2} cm. radius to obey Cunningham's law (8). Meteoric particles settling towards the earth may, therefore, do so inappreciably, collecting together. Volcanic dust may also accumulate, and if these collections occur with an air rarity of 3×10^5 molecules per c.c., the possibility of an inverted natural aerosol, i.e. a solid dispersion medium with an air disperse phase, must be considered.

Other Factors affecting Dust Circulation.—Buys Ballot's law (that in the northern hemisphere with the back to the wind, low pressure will be on the left, high on the right ; in the southern hemisphere, vice versa) whilst controlling the general particle movement, will be constantly counteracted by numerous local and special meteorological effects affecting dust distribution. Thus descending air currents, of cause yet unknown, and generally less powerful than ascending ones, will affect the dust balance set up by the latter ; the trade wind and doldrum regions move with the sun ; deserts have high day winds and calm nights, and dust clouds replacing rain clouds ; mountains have night maximum wind velocity ; low regions day maxima ; tropical weather only receives violent cyclonic variation ; wind velocity is frictionally diminished near the ground (and there is a high to low pressure drift across isobars), increasing greatly with slow direction-change in

next layers, then increasing little with quick direction-change up to, say, 1 km., above which change depends on horizontal temperature change; with light winds night and day maxima are equal at a height of about 16 metres in winter and 16 to 32 metres in summer—Hellman (180)—and as wind diminishes near earth's surface towards early morning, its direction begins to change; at 1 to 1·5 km. height there is no appreciable variation, but at about 1,000 feet a night maximum and a day minimum—Durward (181); continental seasonal seaboard wind variation will depend upon characteristics of prevailing winds; rainfall, hence maximum particle removal, has a maximum about 1·5 km., rising in summer and falling in winter; and temperature changes have considerable effects. Rainfall is the great evidence of vertical upward currents and winds, showing their wide extent and persistence. The horizontal winds largely counteract the effects of the weaker descending air currents. Land temperature variations during the day vary with height from 5 to 9 degrees C., up to about 0·5 km., whilst N. K. Johnson confirmed the "Challenger" conclusion of a daily variation of but 1 degree C. over the sea. On cloudy nights, day and night temperatures are similar, but clear nights produce much lower than day temperatures. Desert variations being excessive produce rapid rock weathering, feeding the persistent dust clouds to their own particle, and further rock, disintegration. Horizontal temperature variations will more powerfully affect the staubosphere in winter than in summer, whilst height decreases land temperature 3 degrees C. per 1,000 ft. This helps to produce katabatic winds which will bring dusts downwards, and whilst clearing the air from humidity and increasing insolation, will yet charge it the more with dusts. Within tropical regions a daily increased pressure morning and evening will discourage particle ascension. Secondary wind systems produce a huge jockeying of pressure between Indian and Pacific Oceans, Northern Pacific, and Iceland and Africa. At about 18 km. over the equator, gradually falling to about 6 km. at the Poles—lower in winter than summer—temperature ceases varying vertically, and varies horizontally. This region is the tropopause, below it the troposphere; above it the stratosphere. But the dust-moving convection currents may be replaced in the stratosphere by horizontal thermal movement, though no dust will be moved by nucleisation since no rain is formed, in general. The great

height to which volcanic dust is forced in the stratosphere has produced red sun-halos—Encyclopædia Britannica (182)—and the reduction in solar radiation being calculated as 20% for a possible dust distribution of about 6×10^{-3} km.,[3] this stratospheric dust distribution has been invoked as a possible explanation of Ice Ages (*cf.* Dust in Geology). If correct, it indicates the unlikelihood of large stratospheric dust accumulation.

Dust particles, along with water vapour, by reducing (about 50% is lost in passing through the atmosphere) have a great effect on the resultant cloudiness and determination of solar, continental, or mountain climates, in different latitudes, which in turn affects their own distribution. The radiation from the sun, or solar constant, at the tropopause is given as 1·95 gram calories per sq. cm. minute by G. Abbot, and the energy of the radiation as $3{\cdot}5 \times 10^{-3}$ erg per sq. cm. per second by E. Regener (183). In addition to the manner in which insolation will affect dust distribution in the staubosphere, its extent and variation will obviously have a decisive effect on the weathering, which is the chief source of earth-formed natural dusts. The temperature scope of insolation, whether exceedingly wide, as suggested by J. Larmor, or comparatively restricted, as counter-suggested by G. C. Simpson (184), is therefore of exceeding importance for the continuing staubosphere. For if wide, weathering during the period would be greatly accelerated; but if remaining narrow—due to varying solar radiation being counteracted by denser cloud formation or complete lack thereof, when solar radiation is respectively greater or less—then the amount of dust would be greatly diminished in the first case owing to the heavy rain of a pluvial epoch, and the reduction of dust-forming agents by the saturation of deserts. But the amount would be greatly increased in the second case owing to lack of use of particles as rain nuclei, and drier, dust-forming nature of the sources of dusts.

There is likely to be an intimate relationship between the staubosphere and the ionosphere, since the units of the former probably each carry some electrical charge, and if the ionosphere varies with the sun's zenith distance and sunspots, and aurora are due to charged particles from the sun penetrating to between several hundred and 90 km., such charged particles will often pass through the meteoric dust-formation region. A. H. Compton (185) inclines to the view that cosmic rays are particles such as electron or proton streams, and in

July, 1933, was arranging for an ascent into the stratosphere, with the hope of gaining further data, the vessel carrying metal dust as ballast—a novel dust use. Ratcliffe and White (186) consider the electric fields in charged rain-cloud neighbourhoods may account for abnormal high reflection from the east region of the Heaviside layer, whilst Appleton and Naismith (187) state that fairly high correlation has been found between high ionisation and thunderstorm activity in the Kennelly-Heaviside layer. The possible connection of charged dust particles with thunderstorms and raindrop formation has already been discussed.

If dust degradation can proceed to molecular dimensions (and the formation of helium nuclei from protons and electrons in space has been suggested), then the finest particles might become ionised by solar radiation, since there are 10^5 free electrons per c.c. between 70 and 150 miles high, and meteoric dust is found at about 94 miles. Nearer the earth the potential gradient, with a maximum in winter and a minimum in summer, has a secondary daily minimum correlated to air currents and charged nuclei. Chree first noticed the close variation of atmospheric pollution with electrical potential gradient. Evidently the connection with dusts is a very close one.

Some interesting experiments on the behaviour of particles thrown into a wind of about 8 m.p.h. were performed by J. A. Udden of Illinois. He found those of practically 10^{-2} cm. radius to be propelled almost horizontally and carried upwards by eddies; $0{\cdot}2 \times 10^{-2}$ cm. radius or less, to be completely borne-up by the wind; those about 4×10^{-2} cm. radius to fall almost vertically. Allowing for the gravitational pull and increased velocity, and for the 33% energy consumption of friction postulated by Amonton's law, these are of the order of effects expected from the foregoing calculation that a wind of $1{\cdot}75$ miles per hour would just move a particle of 10^{-2} cm. radius. O. F. T. Roberts (137), working on eddy diffusion, deduces that the square of standard deviation of matter scattered from a plane source varies as the time. The scatter (of dust particles, for example) from a point, into a medium with uniform medium flow, is thus explained.

Typical Visible Dust Systems and Movements.

Wind systems continually create typical formations with all kinds of visible dusts. It is stated (148), " The most disagree-

able features in the South African climate are undoubtedly the dust storms which occur all over the country. They are most frequent during the second half of the year, usually starting in August, when the high pressure over the interior is beginning to break up ; they are also frequently associated with forefront of advancing thunderstorms so common over the summer rainfall area. The fine dust, raised by a strong, squally wind, rises as an enormous thick cloud, almost blotting out the landscape and penetrating everywhere. Fortunately, these dust storms seldom last for any length of time and are usually followed by rain." Does the huge particle concentration cause the rain, and will the cloud carry huge electrical charges ?—as found by W. A. D. Rudge (149) for similar phenomena—may be inquired ? Other regions experience similar storms. C. W. A. Scott, on the England-Australia flight, April, 1932, was delayed between Baghdad and Basra by dust storms, and the latter place experienced a very fierce sand storm in June, 1933. The cyclonic storm over central Tunis (110) in March, 1901, according to Hellman and Meimardus sucked dust from southern Algerian deserts so high that 600,000 tons (one-third the European deposit) fell north of the Alps, whilst $1 \cdot 5 \times 10^8$ tons fell on the African coast, and a great amount in the Mediterranean. Sven Hedin (150) supplies vivid details of a Gobi desert sandstorm. Abstracts are : " . . . The sky was completely darkened with myriads of flying grains of sand and particles of dust. . . . One must press forward as if through water . . . for the camels it is well-nigh killing. . . . Against my tent there beat not only sand and dust, but a regular drum fire of fine gravel. . . . Light-coloured comet tails of dust and sand wind their way along the ground with the speed of the wind." Dust devils prevail in dry-sand regions —dustspouts, like waterspouts—e.g. round Lahore in April to June. The rotation of this from long observations in Iraq and Lower Egypt has been noted both clockwise and anti-clockwise, though J. Durward considered the variation from complete anti-clockwise may be due to relative positions of observer and dust devil. The British industrial dust horizon, like the Indian blown-sand dust horizon, has particle diameter of about 0·8 micron (152). In Manchester (Whit-week, 1933) heavy iron sheets, stones, roofs, large sand heaps, and a high dust column were raised, and in U.S.A. in February, 1934, cows were seriously damaged by large frozen par-

ticles. Even a summer S.W. breeze has lifted 1,000 feet loose bandstand music sheets (153). The force of dust whirlwinds—not uncommon in the English summer—is thus indicated. Seeds, leaves and dust thus travel far, the foremost over mountain summits to distant valleys even 12½ miles away—Vogler. Scotch streams are whisked to fine spray, turf and sticks transported. Feeble such whirlwinds contrasted with their tropical violence, ploughing wide forest-paths, creating huge dust clouds—for light forest breezes readily disperse spores and seeds. The February, 1881, gale carried much plant debris (implying more dust) over the Cattegat to Eastern Jutland, 70 miles from the Swedish coast—Warming. At 1¼ km. over Mesopotamia airmen encounter still-rising, dust-laden winds. Impalpable volcanic dust would travel far in violent whirlwinds—lifting horses and cattle—such as accompanied the Tombara eruption in 1815. R. M. Williamson (156) refers to clean holes in solid wood made by fragile penetrants as common, in tornadoes like that at Nashville, March 14th, 1933. The Simoom wind often carries huge rotating sand columns. Near Baghdad in 1918 heavy kit moved 200 yards, an officer (with resultant broken ribs) and furniture were carried along by a column. Haboob is the Sudanese equivalent for Simoom. Vast whirling sand columns completely buried Persian troops—History of Herodotus (145, 154)—whilst Angieras in 1915 sheltered by force under a rock for nine days, later having a camel saddle carried 600 yards, in a west Saharan gale—P. A. Buxton (151). Huge dust removal occurs in storms like that awful West-Indian hurricane of September 22nd–30th, 1916, with a 140 m.p.h. wind at the Mississippi mouth. A type chiefly occurring in August to October (157). Huge North-Indian dust storms in April to June disorganize laboratory physical instruments, in addition to general effects.

Resultant on, but more extensive than, dust storms are phenomena like yellow snow, red rain, and Harmattan haze, representing their far-borne, highest, slow-settling, finest dust. Red rains—colouration due to very fine sand—chiefly of Mediterranean and Cape Verde Islands incidence have reached England, Lyons (1846) and Boulogne, and the Canary Islands in 1865—Daubrée. Italian coast window-pane deposits suggest Libyan Desert origin. North Italy received dust alone an inch depth over 1,800 square miles, in addition to the frequent

rain and snow deposits, and in early 1934 red rain fell in the Italian Alps from Saharan dust storms 700 or 800 miles away, terrifying peasants. A. Geikie (158) naming it "red fog," "sea dust," or "Sirocco dust" mentioned sun-obscuration, deck, sail and rigging immersion, sometimes hundreds of miles from land, whilst "blood rain" also describes it. In England (159) 10,000,000 tons was deposited February 21st and 22nd, 1903, originating in N.W. Africa. Bordighera (160) in Italy received red rain, G. H. Bryan kindly supplying a dried sample, which Blacktin found developed an electrical charge on whirling in air—suggestive of the large charges developed by such phenomena.

Yellow snow (hoarfrost being yellow) fell in Silesia in 1931–1932, due to Asiatic desert sand. Russian yellow snow carries dust wind-raised on the Caspian Steppes—C. von Cammerlander (162), black snow at Ruschuk in February, 1929, was due to volcanic dust; $1\frac{1}{2}$ million (solid) tons of mud fell at Lemberg in 1928; and 10^6 tons of dust-coloured snow over Vermont and Iowa, came 1,000 miles from Arizona and New Mexico, before falling (110).

The Harmattan Haze—Harmattan, North-East Saharan and West African winter wind, plus very fine dust it raises—drives its huge sand burden over immense distances, creating thick haze, penetrating all in its path, believed to deposit thick dust even at Western Atlantic limits—W. N. Shaw (145). Immensity of such systems is suggested by the dimensions of a relatively short storm in 1863 depositing 6,500,000 tons on the Canary Islands, the larger one of March, 1901, bringing 1,960,000 and 1,650,000 tons to Europe and North Africa, respectively, covering 300,000 and 170,000 square miles of land and sea, partly having travelled 2,500 miles—A. Grabau (163). Darwin (164) noted dust falls far out at sea; Lyell found infusoria with siliceous plant tissue north of Cape Verd Isles, and 25-micron diameter stone particles, 300 miles from land; A. R. Wallace (165) records Judd's quartz hornblende findings, 100-micron diameter at Genoa in 1885, probably from the 600-mile distant Sahara, and J. Murray's (Challenger Expedition) finding æolian spherical 100-micron diameter particles in deep-sea deposits, 700 miles from Africa or Australia. The Harmattan haze projects 150 miles seaward from North-West Africa, whilst desert air continuously (as well as intermittently) carries much fine dust,

to add to the normal fine staubosphere. Sea falling dust, commonly prevalent from January to April, may have established the "sea of darkness" legend of the Canaries to Cape Verde island region. In 1898, S.S. "Roslin Castle" and "Tintagel Castle" traversed 900 miles of dense haze, and were detained 30 hours, respectively, due to such dust (110). The mass distribution and size of particles in deep sea deposits was studied by Sven Oden in 1910 and 1911. Black carbonaceous industrial rains, artificially derived, do not belong to this section. The huge electrical potentials developed in such dust systems—additional to that previously studied for the permanent staubosphere—must be noted. The Simla electrical sign change from morning to afternoon in June may be atmospheric-dust caused, and perhaps also the minumum morning and maximum evening, sea variations (145), though other causes are not precluded. Huge electrical charges are certainly generated by whirling dust and sand. A forsaken motor car, head-on to a sandstorm at Helouan in the Khamseen season (166) was so highly charged by sand (on its insulating rubber tyres) that a spark-discharge over a foot long gave a severe shock on approach to the handle, succeeded by a second. Driven snow-dust has been shown to create large charges—A. Stager (134)—and lightning over active volcanoes may be caused by their dust electrification. It may be suggested quite generally that wherever dust moves, electric charge is generated. In the severe Kansas storm (March 23rd, 1913), the air being warm, very dry, and dusty, telegraph wires were charged, vegetation killed, wheat turned brown, and sparks 2 or 3 ins. long drawn from a wire to a windmill, the latter, particularly if of steel on wooden mounts, being dangerously charged. Study of the potentialities of these huge, continual generations in all kinds of moving dust systems is conspicuous by its neglect. If lightning is ultimately traceable to dust electrification, the whole problem obviously merits serious study, on account of its great possibilities.

The Entropy of Natural Solid Units.—Constant and continuous dust formation by degradation, each formation being smaller than its immediate predecessor, implies general object individuality loss, unless powerfully counteracted. Growth, with its human simile of artificial object production, will strongly resist this running "down" in the organic realm, so that inorganic objects are its chief butt. But eventually—

assuming continued operation, without supplementation, of present principles—even growth and production are controlled by this entropy. They might be completely destroyed if desert examples became generalized. Growth necessitates rain. In many deserts, e.g. the Libyan, the desert is due to rain-lack, although its consequent dust supplies makes rain, hence the counteracting growth, possible in other regions. In the deserts themselves, the growth tendency has been destroyed before disintegration, or "running-down," is complete. For some rocks still defy north-wind erosion in the Libyan Desert, though the sole sign of life over the vast, sandy plains are snakes dependent on weak, migrating birds forced down, for maintaining life—R. A. Bagnold (169). Skeletons of incomputable age witness the degradative triumph over counteracting tendencies, as also the severe lack of water. Similarly, the stone implements of ancient unknown peoples, and their ashes and refuse mixed with the sand. The inorganic building up from degraded particles still requires some cataclysm to transmute them to larger individual objects, emphasizing the strength of disintegration. Thus, the fine dust, sand and mixed decayed vegetation found accumulated to 20 ft. depth over Assyrian building foundations at Kouyunjik by Layard (170), blown from the plains, has evidently shown no sign of building up. Sedimentary rocks—still, however, characterized by sand-grain units—are the chief exception.

The natural tendency, therefore, is for objects of definite form to suffer gradual degradation towards uniform size level. Or, for form distinction to pass from macroscopic to microscopic dimension. Dust electrification may assist by holding particles apart whilst the process continues. Aerosols imply continuing degradation. Aerogels, but a preliminary stage of counteraction. As molecules may be regarded as the finest independent particles, electrical holding apart will be continued indefinitely. Dust particles, under the degradative procedure, must get more and more numerous and finer and finer in average dimension. The logical climax is ultimate, general, disintegration to molecular dimension. All would then be gaseous, including what were liquids, for nuclei being nonexistent, vaporization would not be followed by condensation. A fitting and appropriate end to a system originally supposed gaseous; coinciding with natural tendency to maxima and minima; and supporting known thermodynamic operation

as original hot gases would finish as final cold gases. Degradation and mutual attrition, assisted in the ways discussed, are tending to this general level of physical refinement.

Dust Before, In, and After Rainfall.—Water supersaturation of 8 must supersede raindrop formation on ions. Most will, therefore, occur on dust nuclei of all kinds, as also fog and mist formation. Such solid nuclei may be water soluble or insoluble. With city carbonaceous dusts, nuclei will be chiefly insoluble; over siliceous dust regions also; whilst over oceans, large seas, mountains, etc., chiefly soluble, whether ice, snow, or salt particles. Considered together, nuclei variations are legion, though regionally largely determined by local characteristics. Shaw and Owens (130) favour selectivity of soluble particles.

In falling, precipitation transports the nuclei of its units. Of whatever nature, therefore, rain is more rapidly moving dust from the atmosphere (depleting the staubosphere) than dry settlement could. To this precipitated fraction of the staubosphere one of three things will happen, dependent on whether particles are (*a*) partially soluble; (*b*) insoluble; or (*c*) completely soluble. Degree of solubility will have various effect in varying conditions. Insoluble particles will be left upon the object receiving the drops; or be carried away with the liquid stream, when they may either settle out at some other point (being later air-raised again, thus completing a cycle), or be carried to rivers or seas either to circulate or settle in their beds. Completely soluble particles will totally disappear in falling and resting upon an object, and being carried in solution in the rainfall, be either deposited by vaporization in other locations, or remain in solution in seas and rivers. In the former case, they will be again wind-raised. In the latter, augmenting the dissolved salts from which first formed, probably, their substance will be again available for particle formation. This will also complete a cycle, with assistance of dissolution and fresh formation. The only modification with insoluble particles will be one of size, shape, etc. Partially soluble particles will partially follow both the preceding cycles, insoluble portions often retaining some attached soluble portion. All degrees of solubility will be covered by the great particle population variety, e.g., an obscure substance like white butterfly-wing dust, shown by F. Gowland Hopkins to consist of uric acid, or, in the vegetable kingdom, the white

dust from auricula ("dusty miller") leaves. The range of possibility is amazing.

Save for slightly dissolved gases, rain water, always pure on immediate formation, will hardly ever be so after falling, for in addition to a raindrop's essential nucleus, it will have a falling dissolution history of its own concerning other soluble particles. Its composition, and consequently its capacity for varying it, will vary whilst falling. With this constant and large rain-nuclei addition, all waters must contain vast particle additions in addition to those directly settled therein, or stirred or moved from bed to bed, or dissolved from their own beds. Such suspensions form an immense and continuous outlet for particles from world dust systems, and geological changes may re-liberate such accumulated suspensions for renewed gradual re-addition to the earth's staubosphere. Such suspensions, circulating; sedimented to slime or ooze in the deep sea; or silt in estuaries and river beds, are added by direct wind action and gravitational settling as well as raindrop nucleization. One or other of these causes operates at every point. They are actually competitive. A wind will prevent normal settling in one place transferring some of its dust to another locality, perhaps to arrive slower, perhaps faster, at its final destination. This wind-borne effect is superimposed on normal, general, steady settling, and dusts driven down to water suspension will be thus augmented in some, depleted in other, localities. The low-pressure equatorial, and high-pressure tropical, calms will be regions of quiet water-suspension addition. The world-wind paths scenes of particles borne into water-suspension by air currents. Subject, therefore, to the interference on settling of water currents themselves, there may be a piling-up on sea and ocean beds in certain areas where quiet settling has not exclusively occurred. Thus ocean, river, and sea beds are probably being moulded by passage from air suspension of dusts, to water suspension, under the direction of rains, winds, and normal settling. Mountains (sedimentary) and valleys of future geological eras may thus partially be moulded, just as the industrial activity of this present kainozoic era is enacted on the sedimentary deposits of previous eras.

Whilst facilitating rainfall, dust rids and cleans the atmosphere of its own presence—desirable where so dense as to produce pollution or ultraviolet starvation. A certain balance

of dust supply and removal is, however, essential. For dust lack would be serious as is dust excess. Dust in its natural function destroys dust in its artificial function. Noxious, as such, with rainfall it produces its own desirable expulsion. Rainfall neighbourhood will largely affect rainfall effect. Where the nuclei are industrial carbonaceous or metallic, and air and surroundings unpleasant and dirty, rainfall—though redistributing it—will help to increase the dirtiness. Whilst where nuclei are water-soluble, with air and surroundings relatively pleasant and clean, no increase due to rain deposit (as in the former case) will leave the rain free for further cleansing. This definite distinction, cumulative, enhances the sociological effect due to wind distribution, keeping clean districts clean, and making dirty districts dirtier. Dust nuclei and water vapour are, respectively, precipitator and precipitant. The generally-accepted rainfall cycle is vaporization from water surfaces by the sun, then precipitation of such vapour as rain, and eventual return to the source. The agency of precipitation, the necessity of nuclei of some kind, is generally not realized. Without dust intervention—whilst some rain might still be formed on ions, molecules, or molecular aggregates—rainfall, and consequently most life on the globe would disappear. In other modes also life is dependent on dust particles. The desirable restatement of the rainfall cycle should include definite reference to the indispensable function of dust.

There is a continuous and ceaseless conspiracy between water and dust (both assisted by wind) for the former to get back to the oceans, and for the latter to get to the oceans. The key to the success of this conspiracy is rainfall, with dust as moisture precipitator, moisture as dust particle precipitant. Examples of its operation are the lengthening of all great rivers by the extension of their deltas due to particle deposition from their waters. Such sea-water coagulation of the suspended particles is supposed to have added 1,000 miles to the length of the Mississippi (110)

The Earth's Dust Load.—Sea floors and channels have been depressed by sudden access of weight of the superior water. The north polar movement over a small region is supposed due to snow piling at one limb to detriment of another—J. W. Gregory (469). The high Himalaya are thought to be becoming still higher, due to land movement. Such results suggest con-

siderably greater effects on the underlying surface due to the weight and irregular distribution of the earth's dust load. Large dust transferences must affect such a balance, e.g. that which must have happened in the westerly gale of April 2nd, 1933, which swept the British north midlands, and typical of many such. Thus in two great cities 40 miles apart, continuous dust clouds were moving rapidly across open spaces and streets, filling them house-high, and transporting huge dust loads further east. The typical west-to-east movement of industrial dusts in England was well represented by this occasion.

CHAPTER V

DUST IN EVERYDAY EXPERIENCE

SUBDIVISION.

FOR the great majority, life's experiences are a varying mixture, (*a*) within walls and under a roof, and (*b*) outside walls and buildings. Primary division will, therefore, be into (*a*) internal experiences, and (*b*) external experiences. Subdivision will refer to human activities involving dust incidence, whether (1) essential, or (2) incidental. Complete subdivision will, therefore, be into four principal sections, viz. :

(1) External essential circumstances ;
(2) External incidental circumstances ;
(3) Internal essential circumstances ; and
(4) Internal incidental circumstances.

A fifth—General—principal section will precede the others.

GENERAL DUST EXPERIENCE.

Where a substance exists in a generally intimate as well as widespread manner, it will probably approach fundamental vital necessity. This, recognized regarding air, must have been always known, though its chemical nature was not, emphasizing present and past apathy concerning staubospheric knowledge, of vital significance. Whilst within reasonable temperature, pressure, and wind-force limits, the atmosphere everywhere contains constant permanent gas (e.g. oxygen, nitrogen) proportions—S. Chapman (155)—the staubosphere may show violent variation in content, though research indicates its atmosphere-wide existence. Quick and thorough realization that all earthly life—human, animal, vegetable, or microscopic, without even momentary escape, night and day—is dust-immersed is desirable. As most life would cease on atmosphere removal, so almost certainly would it with staubosphere removal. It is debatable which is the more essential,

For the benefits of neither could be enjoyed in the absence of the other. Staubosphere removal would practically destroy light, and largely rainfall. How important, then, largely-neglected dust studies—though pursued in some specialized directions.

Dust is pregnant with serious possibilities for humanity.

Whether it be visible, is the general criterion of dust existence for the multitude. D. Brunt (411) defines dust as earth or other solid matter in a fine state of subdivision so that the particles are light enough to be easily raised and carried as a cloud by the wind. But " very clear " air may contain from 30,000 to 60,000 particles per c.c. in a city, which the majority would affirm from the obvious test of visibility or wind-raising not to exist. Yet it reduces the limit of visibility in London to, say, a half mile. Her crowds hardly regard that hazy, diaphanous effect as a dust effect. Yet a mere 2,000 particles per c.c. will obscure a mountain at 50 miles distance, whilst 100,000 per c.c. would make invisible objects a mile distant—J. N. Friend (188). A breeze, raising visible road dust, is the common criterion of dustiness, though that may have added but 1,000 particles per c.c. to the 30,000 to 60,000 already mentioned. The 1,000 make their individual presence more felt. Minorities decide the issue. People avoid such large-scale empirical dust, observable through the unassisted senses, but almost totally acquiesce in their continuous immersion in impalpable dust clouds of scientifically-determined amount. The 37% sunshine loss in London owing to dust and smoke, with 10% loss even at Kew by London pollution—J. N. Friend (188)—though in 1916–1920 London and Westminster registered 53% of the Kew sunshine figure, increased from 20% in 1881–1885, is all due to the impalpable dust factor. J. Alexander (110) suggests the possibility of modifying the atmospheric condition of a city like London by attention to the now-ignored production of nuclei. This numerous, fine factor is the real ever-present staubosphere of which the occasionally visible portion is but the earnest. Its persistence, extent and amount cause it to be chiefly charged with major good or evil effect for mankind. Visible, spasmodic, of small significance, the one factor; invisible, continuous, of great significance, the other; relatively.

It is deplorable that the majority should not realize that their water supplies, their very existence, are available largely

because of the staubosphere. For its necessity is largely coincident with the necessity of rainfall.

Important everyday implications arise, in addition to its existence, from its variation with locality. Thus, no two individuals have identical dust experience. As one carries always a different fingerprint, a different cranial contour from every other, so he has a different dust experience. Had the staubosphere one common value in particle number or kind, this could hardly be. It decidedly has not. A whole gamut of gradations from relatively sparse (over oceans and mountains) to relatively dense volume value (over cities, in coal mines) exists. J. S. Owens (130) in 1923–1924 gives 40 to 4,300; 300 to 60,000; 59 to 1,785 per c.c. in Athens, London and Washington, respectively; E. D. Fridlander (189)—using Aitken's dust counter—243; 245; 280; 280; 383; 875; over 2,000 per c.c. over Indian, Pacific Oceans; Gulf of St. Lawrence; Arabian Sea; Red Sea; Mediterranean; and Atlantic Ocean, respectively, and at Bieshorn (Switzerland) summit, 157 per c.c.; whilst G. Melander, Helsingfors, 1897, found nothing less than 300 per c.c. in Switzerland, Biskra, Norway, Finland, or Russian borders, and often a high maximum. The significance of such variations is great from medical, hygienic, or mere comfort viewpoints, in the medical sense often becoming a matter of life and death, or ill-health and economic compensation, whilst longevity at least is often seriously affected. A. E. Crossley states (523) over 12% annual deaths in Great Britain are through pulmonary disease, the respiratory disease death-rate increasing 100% four to six weeks after a fog spell. If not expelled internally and phagocytically from the lungs, or through mouth or nose, dust must accumulate therein, and the fact that in cities like Manchester winter sunshine is but 50% of that in the environments will assist harmful effects. Fog-filtering bags used industrially near Manchester become quite black in a month. Despite thermal precipitation driving particles from warmer to cooler settling grounds, all lungs become more or less dust-charged. Thus Lehmann—1912—showed 40% dust from air if nose-breathing, and 80% if mouth-breathing, retained in lungs or stomach—J. N. Friend (188).

A mountaineer enjoying practically dust-free outside experience will suffer greater dust contamination at home—particularly in winter. But a miner's house—considerably more dust-

charged—will provide insignificant dust experience, contrasted with his work. The respectively pink, unpetrified lung; and practically solid black lung; cumulatively produced, afford evidence. Two people may have identical dust experience in the same house, but very appreciable variation will be introduced by one going to work in a much dustier laboratory or office. But, although it is stated (Office Regulations Bill) that almost 25% of office workers die of pulmonary diseases, new methods of air conditioning claimed to transform office air into "mountain air" and rapidly improve health, are likely to reverse the foregoing variation. A coal miner, flour mill operative and road sweeper might occupy one house. Owing to the exceedingly varied working dust experience, cumulative effects will be greatly different. Polar, or hot-desert life, well-immersed in varied dusts, agree in chiefly lacking a particular kind—bacterial. Ocean air is similarly healthy, but because of lack of almost all dust save salt particles. Iron, steel, and blast furnace centres produce iron oxide air dust, and soot and smoke may definitely affect bacteria. Legion will be the varieties of dust experience, as of kinds of dusts, and mixtures thereof.

Humanity has no escape from the constant, continuous visible and invisible, variable staubosphere—from birth to death. For the earth contains no known quite dust-free place. Immense, difficultly-assessable sociological implications arise for—save, perhaps, the high stratosphere—illimitable dust prevalence leaves no dust-free base-line standard. Contrast of general human temper at sea-border and inland may be a criterion. If rather considered as contrast between pleasure and work, then pleasure, equally with work, depends on health—increased by sea-border air, better largely because cleaner, i.e. more dust-free. Ozone is not alone in conferring beneficence. Finally, state of mind is largely determined by physical condition, itself affected by dust. With eyes attacked; teeth gritted; and general physical malaise, the industrial-city east end drives home its fretting annoyance, invoked by dust, acid fumes, and smoke-laden air. The lung retention thereof, so appreciable, assists.

In what ways does man produce his own share of dust undoing? Wherever foot treads—immensely oftener in city than country—dust is raised; wherever people sit, dust is disturbed. Dispersed constantly from clothing in walking;

constantly and increasingly raised by wheels; borne by air currents under their chassis; dust, with smoke, is constantly disseminated from chimneys. Napoleon's armies crossing Europe to the Battle of Austerlitz received orders to avoid dense and overpowering dust-production by straw-chewing.

Cities suffer constant dust-circulation between air and ground under the whip of traffic streams. Passing vehicles, people inhale street refuse and other dust, as do the occupants. Multifarious human movements and activities raise dusts, forming a never wholly-eradicable vicious circle. Such dust is added to the naturally-produced complement. Aitken (28) showed air-dust haze in inhabited parts to equal that from uninhabited × 10.

In west wind prevalence countries, e.g. England, a general west to east dust movement—with slight direction variation from summer to winter—will obtain. Locally this spells general east-end city dust disposition which determines sociological population distribution. For industrial dust-producing units are operated in east and south-east, where their own, and western, domestic smokes are added and deposited. West and east dust distinction is therefore most marked, witnessed by the most noticeable bouleversement when, occasionally, wind reversing direction, city-warmed, dirty east-end air assaults the west. This dust distinction—vast, since cumulative—often markedly characterizes dwellings and habitants from east to west, largely explaining physical health, mental attitude and outlook contrasts, and producing political repercussions. C. M. Smith (532) states a 5% higher pneumonic death-rate amongst poor class people in Glasgow than the city rate, whilst pneumonia causes more deaths than any other acute affection in this country.

Each individual, each vehicle, is a potential and actual dust stirrer. Collections of both on sites where previous generations dust-produced, supplement and amass dusts there preferentially. Dust experiences there will possess historic intensity, without ceasing variation in their particular dust class. Lungs of such massed city dwellers are, however, typical, due to concentrated dust experience—though individually variant. Dependent on degree; kinds introduced from environs, from selectivity or specialty of manufacture suggested by geographical position; quantity and type of dust will

vary from city to city. If, say, 20 or more miles apart, the larger proportion of dust (by weight) will probably settle before one city—wind direction being suitable—contaminates a second. With several small cities or towns relatively close, relative position will apportion contamination, not affected by rainfall if insoluble, e.g. carbonaceous and tarry dusts, are not rain-precipitated, as Shaw and Owens (130) conclude. If widely applied, dust, including much other matter, will partially be washed down. For some regard organic, inorganic, and living germ dust as washed down, including fine terrestrial dust, and probably cosmic spherules of iron—A. Geikie (158). Stored rain water develops putridity owing to organic content. Sign of electrical charge carried by dispersed dust is now believed to decide whether wetting will be by water or oils, positively-charged preferring water. This will prove a criterion as regards rain-wetting. Domestic chimney smokes often appear to blow through heavy rain without wetting. In many countries industrial dusts, replaced by natural, are conspicuous by their absence. The less-massed humanity and vehicles ; less modern devices (e.g. primitive vehicles) will assist natural dust production, piloted by prevailing winds, and determined by particle size. Industrial-country dusts will soil and disfigure more, whilst non-industrial-country siliceous dusts in the east will damage more individuals (particularly lungs) and objects. Of great importance, on account of known lung-retention, and less thermal gradient in hotter climates. Active volcanic dust is generally foreign to industrial countries. Such dust, often carried world-over, in the upper atmosphere may produce particularly beautiful skies, whilst in their emitted neighbourhoods, often sources of distress and danger immediately and for long-succeeding periods. In the Peléean (dust-producing) type of volcano, dangerous dust effects on the mucous membrane are often produced, added to the dust nuisance. Several South African witnesses (190) record respective impressions of beautiful sunsets, sky effects, prolonged daylight, etc., and E. Kidson suggested the dust had travelled with the prevailing westerlies to New Zealand, probably causing low temperatures due to their heat absorption in May, resulting from the South American Andeean eruptions in April, 1932. Volcanoes stretching over 200 miles were active, depositing deep dust in Curico, Chile, and some in Buenos Aires and Monte Video, distant, respectively, about

50 miles N.W., 700 and 800 miles. Three thousand tons of pale, greyish dust fell in a day in Buenos Aires.

SPECIAL DUST EXPERIENCE.

External Essential Circumstances (1).—Queen Elizabeth, according to F. G. Cottrell, prohibited coal-burning during London parliamentary sessions, though earlier, in 1306, it was royally forbidden. The Railway Clauses Act, 1845, and Town Improvement Act, 1847, had clauses for self smoke-consumption. A comparison method for quantitatively determining fine soot inhaled was advanced by A. I. Burstein (507), whilst White (450) discusses smoke effect on health, which perhaps lacking, in direct immediate danger, does indirect harm to breathing, through ultra-violet deficiency, and discomfort. Smoke concentration varies from 0 to 3 mgm. per c.m., J. S. Owens and associates (193) having correlated particle number; mgms. per c.m.; and resultant light obstruction with the Contrast Photometer. Routine British Air Ministry records of some smoke pollution are made. W. Nicholson (194) deals with practical smoke inspection, and O. Klotz and colleagues studied smoke-problem hygiene since 1911 for the Mellon Institute of Industrial Research, Pittsburgh, producing standard reference work—Meller (197)—who refers also to the aggressive enterprise induced by bright, clear days; vitamin-starvation. effects of polluted air; and anthracosis and fibrosis in confirmed city dwellers. The Mellon Institute, 1912–1914 survey, shows close relationship in Pittsburgh between pneumonia and smoke prevalence, though C. Schade (470) concludes sulphur dioxide there too small to cause health concern. Soot may act beneficially, adsorbing bacteria, whilst inhibiting bactericidal sunlight action, though Cohen and Ruston (213) quote Ascher that soot and smoke increase the death rate via acute lung disease. Mellon Institute smoke, solid matter, and acid surveys in Pittsburgh in 1912–1913, 1923–1924, and 1929–1930 showed 70% decrease in second period over first, with a dust increase of 40% and an acid increase. All-round decrease was shown by third over second period, despite population increase of 1% from 1910 to 1930. The dust decrease probably due to factory transference might simultaneously imply exclusion of more sunlight from the city. Legislation, establishing a world-wide precedent, followed the first survey, Pittsburgh adopting in 1914 an anti-smoke ordinance based on Ringelmann

No. 3 density chart, i.e. 60% smoke, opaque on leaving stack. Special sootfall studies were made in St. Louis, Cinncinnati and Pittsburgh in 1916, and special surveys have been made in New York, Chicago, Salt Lake City, Boston, and Baltimore. Anti-smoke ordinances have been adopted in 125 U.S.A. cities of over 30,000 population. In Great Britain systematic surveys have been carried out since 1914 by the Atmospheric Pollution Committee, following the Coal Smoke Abatement Conference of 1912, whilst 79 deposit gauges were being operated by 34 different authorities in 1927. Meller finds the average soot loss from domestic over 6%; from boiler-plant fuel less than 1%; Roberts-Austen and Cohen and Hefford found 6% average; Sinnatt in Manchester but 2%; and Scheiner-Kestner less than 1% for boiler furnaces. Whilst a smoke stack may have a smoke range of, say, half mile radius, if smoke from a 50-ft. stack trails up to a height of, say, 300 ft., whilst from a 300-ft. stack it trails horizontally, the floor length covered is greater with the latter. Emission-direction in all cases may suffer some angular change from moment to moment, till the whole circular area is covered with some deposit, a shadow zone (deposit-free) near the stack being offset at the circumference. In a city like Sheffield, area, say, 53 square miles, with, roughly estimated, 50% area outside the stack region, about 26 square miles must be covered, requiring but 26 stacks. The actual number is very much greater, but regarding Sheffield as an extreme case in England, as Pittsburgh may be in U.S.A., complete covering by smoke-stack turnout deposit in all purely industrial areas may be assumed, in a given time. Subject to prevailing wind effect, industrial areas will probably experience continuous chimney-stack showers. The difficulty experienced by H. B. Meller (197*c*) in finding stack-contamination-free stations confirms this. The Electricity Commissioners Committee Report (146), taking electric power stations as representative, particular outputs will depend on kind of fuel and type of firing used. Pulverized fuel produces more ash and grit than stoker-fired solid fuel, whilst combustion conditions and unit design also intrude. A pulverized fuel of 12% ash emits 2·62 grain of grit per cubic foot; stoker-fired, but 0·3 grain. Varying from chimney to chimney, a hypothetical case of 100,000 cubic feet per minute would give 262,000 grain of grit with pulverized fuel, preventive means not taken—probably the generality.

Continuous 8-hour smoke emission would thus deposit on the mile-diameter circle about 7 ton. Or over 26 square miles, 232 ton, i.e. 9 ton per square mile. A corresponding minimum of 25 ton per day would be given by stoker-firing. Actually, the potential (i.e. hypothetical) amount will probably lie between these figues, but, in any case, the real amount must be immense, though smoke emission is not, in general, 8-hour continuous. Ashington (England) (147) had 2·05 ton per day in 1932, and Woods Run, Pittsburgh, Pa., 7·6 ton per square mile per day in 1923–1924 (197*d*). In the worst industrial regions, one need but rest a hand momentarily on white paper, to produce its trace in grit and dust. A. Marsh (524), discussing "aerial sewage," states the coal smoke nuisance costs the West Riding of Yorkshire about £6,000,000 per annum. "Historical buildings . . . —York Minster, for one—are actually being eaten away through the carelessness or blindness of our latter-day barbarians. Steps must be taken to ensure that England does not become one vast slum dirt-covered and darkened beneath the aerial sewage." All dust evolved will not fall in the above mile-diameter area. Particles less than 70 to 80 micron diameter will carry further, being deposited in other source areas down to 20-micron diameter, and about 17 miles. Grit from ash of fused density 1·3, a carrying-wind of 10 miles per hour, and a 300-ft. stack were considered. Many particles will be carried right to city environs opposite prevailing wind direction. Less than 20-micron diameter particles may travel very long distances. Less-sized particles may be original smoke particles (not dust or grit) or different-sized agglomerates thereof. Smoke output—gradually becoming dust—is, therefore, reserved for other cities, neighbourhoods or countries in its advancing path, industrial grit and dust for the industrial city itself. H. A. des Voeux (195) stated that Norwich (2 miles diameter) atmospheric pollution was significant for an annual average downwind distance of 5 or 6 miles, deducing for an urban area (of similarly relatively clean habit) of 24 miles diameter, measurable effects for 60 or 70 miles—assuming effects proportionate to productions. The conference addressed resolved that where open fire ranges are installed, "they should be of a type capable of burning smokeless fuel, and urged the Minister of Health to investigate the position and make recommendations to the authorities concerned as to his findings," and urged

local authorities to aim at the greatest practicable degree of smokelessness on all new housing estates.

Size and Settlement of Particles.—If general smoke-particle size is about 0·5 micron—Shaw and Owens (130)—so that allowing for agglomeration, 20 micron represents a very high limiting case, they will travel much further than 17 miles. For, in a still atmosphere, such particles will be just within the ambit of Stokes' law. Ignoring air density, and supposing particles of unit density, this becomes:

$$V = R^2 \times 12 \times 10^5$$

where R is particle radius, and V velocity of fall. Particles of 1·0 micron diameter would thus fall with velocity 0·003 cm. per second requiring 866·6 hours to fall 300 feet, and, in a wind of 10 miles per hour, first travelling 8,666 miles. The sphere of influence of city smoke is thus immense.

It is estimated (146) that of the total particle output (including smoke) 49·5% are larger than 20 micron diameter, which proportion may settle within 17 miles. About half the residue, 25·25%, will settle within a distance of 69 miles, and the remaining 25·25% within any distance up to, say, 8,666 miles. Such estimates apply to pulverized fuel firing under the given conditions. Considering such, it seems anomalous that building fabric should be extremely backened by local atmospheric deposits—even including domestic smokes. In Sheffield, a central white glazed-tile building requires complete annual washing. The alkaline solution used (steam being unnecessary), in completely cleaning, forms a black colloidal suspension. Either the deposit carries little tar or the alkali overcomes wetting resistance. No suggestion of grit, but every appearance of smoke particles is presented. Such blackening is typical.

Whilst allowance for different height and location of house chimneys compared with stacks arises, it is difficult to believe complete smoke-particle movement is presented by the above figures. Probably where buildings arrest the progressing smoke particles, even unagglomerated particles adhere to the fabric. Or, additionally or alternatively, smoke particles may often pursue a circular path under air current or other meteorologic influence, thus gradually settling in their originating neighbourhood. The important composition difference between factory and domestic smokes, showing large ash percentage and

practically no tar for the former, but very little ash, and about 40% tar, for the latter, may encourage domestic smoke adherence to buildings, even without tarry appearance. Thermal precipitation alone would probably induce particles of 0·5 micron to adhere to large objects cooler than the air, though when warmer, the same principle might discourage adherence. The relative warmth of cities will create convection currents. These will tend to lift smoke particles whilst travelling, when, if not meeting higher and cooler air to fall again, they will be borne forward with enhanced altitude. When, at night, the temperature gradient is levelled out—and often inversion will occur—their ordinary downwind travel will be less hindered. But whilst sweeping up and down over a city, greater opportunity to adhere to buildings will have been offered, particularly in view of thermal precipitation. In such ways buildings are blackened by their own local smokes. Small as are the particles they quit, rather than flow with, the air stream, for the walls, taking a direction tangential to their first flow. Otherwise, walls would remain perfectly clean—excepting precipitation deposits.

Shaw and Owens (130) give the formula—for London only—

$$I = \frac{0 \cdot 55}{V} + 0 \cdot 27$$

where I is intensity of impurity in mgm. per c.m. and V wind velocity in metres per second, for particle removal by wind.

The air above a city is hardly likely to reach a state of convective equilibrium, which occurs with normal adiabatic cooling with height, thus:

$$\log \frac{t_1}{t_0} = 0 \cdot 29 \log \frac{p_1}{p_0}$$

where t_0 and t_1 are initial, and final, temperature absolute, and p_0 p_1 corresponding pressures which represents a falling temperature gradient of 1 degree C. per 100 metres height, except possibly at night in absence of inversion. This normal convection effect which would, in any case, tend to lift small particles, will be greatly enhanced by the artificial city convection during daylight hours. Such daytime convection, and the nearer-ground-surface daytime wind pressure will combine effects when particle content is a maximum, i.e. during day. Air eddy currents will discourage normal Stokes'

law settling keeping particles suspended, including large agglomerates such as "smuts," whose "effective" density will, as distinct from their size, keep them within Stokes' law ambit.

Smoke and Dust Control and Measurement.—In a rising smoke cloud in still air, the particles—mobile under brownian movement—will be further, convection-current lifted, many, thus moving upward and outward, not agglomerating. On the outer fringe, mobility will cause them constantly to leave the cloud. Cloud-centre particles, warmer, and consequently more mobile, will maintain this movement, such central particles tending fringewards—a modification of thermal precipitation. Simultaneously, internal rising particles will coagulate, the agglomerates settling to thin the cloud. Fringe dispersion and settling will gradually dissipate the cloud. The very fine mobile particles from the fringe will, probably, never settle. The assessable residue will, therefore, be chiefly agglomerates or smuts.

The "Orsat" apparatus for automatic gas and smoke analysis is supplemented by three different forms of apparatus invented by G. J. Shott, respectively named: "Co Coo," "Duplex Mono" and "Unographe," the first two being considered to give analogous results to the "Orsat" method. In 1924 the Health Committee of the International Chemical Union suggested fixing maximum acidity coefficients, expressed as sulphur dioxide, for smoke at the moment of dispersal, as 5, 8 and 6 gram per c.c. in Germany, Great Britain and Italy, respectively. A proposal from Denmark that smoke and gas acidity (except from carbon monoxide) be expressed in equivalent grams was accepted by the Committee in 1925. The permitted maximum for each country was 0·16 equivalent grams per c.m. at 0 degrees C. and 760 mm. pressure, expressed at rate per c.m. measured at the dispersal point. These measures are suggestive of the possible annoyance to one country caused by the smoke and dust of another.

A community campaign plan against air pollution in cities has been advanced by H. B. Meller (197). This is to divide the "smoke area" into districts, each to be then surveyed for (*a*) sootfall, (*b*) air-borne solids, (*c*) sulphur dioxide, followed by inquiries into efficiency and cleanliness of industrial plants. On the basis provided, regulations would be framed to control (1) selection of boilers, furnaces and automatic feeds to elimi-

nate *dense* smoke, (2) alteration and repairs of plant to achieve the recognized degree of smokelessness, and (3) use of dust separators. Thus reducing pollution.

In England a special committee from 19 local authorities —the West Lancashire and Cheshire Regional Smoke Abatement Committee—has been formed to carry out research on smoke abatement questions, with results to be published, perhaps semi-annually. Varying types of fuel and furnaces are to be studied ; unification in administration of smoke laws aimed-at ; distribution of literature and a spirit of mutual helpfulness promoted ; and sanitary science classes and lectures on smoke abatement, fuel economy, etc., by practical men, projected. The Coal Utilization Council are also seeking a device to consume smoke before it reaches the chimney. The reports of the 1924 and 1926 Smoke Abatement Conferences of the Smoke Abatement League of Great Britain, and reports of the Symposium on Solid Smokeless Fuel (Society of Chemical Industry, 1925) provide further information on smoke problems.

By Act of Parliament of December 15th, 1926—which modified that of 1875—" smoke " includes soot, ashes and cinders also, and " black smoke " provisions must also apply to these. For London, the Public Health (London) Act, 1891, had dealt with the smoke problem, and the City has been responsible for household rubbish since 1670—five years after the Great Plague—when dustmen first started to move household rubbish put out overnight. The 1926 Act necessitates local authorities defining the phrase " smoke causing inconvenience." In France, the smoke nuisance is approached differently, being split into the consideration of dangerous and other trades, differing regulations applying to either. A Seine Department order of June, 1898, prohibits, in Paris, continued emission of thick, black, smoke. But generally, on the continent, the industrial revolution having later arrived, the smoke problem has permitted of greater pre-determination. Continental legislation can be studied in Command Paper 2347—1905. In Liverpool, Sheffield and Manchester there are, respectively, 4, 6 and 5 inspectors for applying smoke abatement measures, and in Manchester also a special committee for public instruction, whilst the London Joint Committee on Smoke Abatement in 1927 were considering a scheme for the education of stokers in connection with smoke production. P. Drinker

(196) states that, owing to 500,000 tons annual consumption of a bituminous coal of 42% volatile matter in Salt Lake City, the State of Utah, in co-operation with the town and the Bureau of Mines, in 1919 voted an annuity of 15,000 dollars for an observation centre connected with the Municipal Telephone system. A first warning to an offending factory is followed by a persuasive and inquiring visit from an inspector. The resultant dimunition has reached a figure of 85%. An Act of November, 1920, prohibits emission for over 1 minute in 30 of smoke of density No. 3 Ringelmann mesh.

Significance of Typical Modern Dusts.—The almost-complete change from animal-drawn to motor traffic has introduced, in a time too short for full realization, a huge, new factor into everyday dust experience. Its implications—accelerated living and working, with consequent higher proportion vehicle-use—are equally important. The Royal Commission on motor-cars engaged to report on alleged injury to roads thereby, found after 41 meetings and examination of 122 witnesses, that it had chiefly dealt with road condition and dust formed. Horse-drawn vehicles still persist for certain heavy traffic, and a reinstatement thereof for short journeys and numerous halts exists. A large firm finds coal delivery thereby less than two-thirds as expensive as motors. Liverpool Corporation still uses about 370 horses. Disintegrated working-animal refuse dust has been relatively obliterated, replaced by a huge new rubber dust population. Dust inhaled is, consequently quite different now from, say, 30 years ago. Correlation with possible change in, say epidemic diseases, may arise, since 40% inhaled dusts are body-retained. Despite this huge turnover, animal dust is still largely observable in such corners and surface-breaks of streets and buildings where wind eddies and other compellents play. An upward glance at the streaming traffic restores the balance.

The huge amounts of tyre and sole-worn rubber dusts are supplemented by car exhaust dusts—mostly carbonaceous—or resultant from previous road dusts through carburettor, sump and combustion chamber. The exhaust output—a quite-large daily complement-like chimney and stack output originates in fuel-consumed power production. Air transport increasingly adds, at all height levels, this fine carbon dust to the staubosphere. Like rubber dust, it is typical of the modern change-over. Compressed dust removed by " decarbonising " analo-

gizes flue stack-dust; larger exhaust particlcs, emitted stack grit; finest exhaust particles, chimney smoke. Practically all cars run on too-theoretically rich a fuel mixture of, say, 10%.

The United States may have 20,000,000 motor cars, and the British Isles licensed 2,196,100 in 1931, showing a total annual wear of, say, 8,000,000 tyres in Britain, and 80,000,000 in U.S.A. If an average of 28 ins. diameter, 4 ins. tread, and $\frac{1}{2}$ in. rubber thickness per tyre be taken, rubber volume per tyre is 180 cubic inches. With average particle diameter 20 micron—probably very high—and volume $4{\cdot}1 \times 10^{-9}$ c.c., all supposed spherical, a tyre will provide approximately $7{\cdot}5 \times 10^{11}$, i.e. 750,000,000,000 particles. The annual number of rubber particles formed in Britain will, therefore, be of the order 6×10^{18}, or 6,000,000,000,000,000,000, and in the U.S.A. 60,000,000,000,000,000,000. The population being roughly 45 millions in Britain, rubber particles per head of population formed per annum is, $1{\cdot}33 \times 10^{11}$, or 133,000,000,000. If the approximate average number of inspirations per minute is, say, 20, there are 9,600, say, 10,000 per person per 8-hour day, and since an individual breathes about 2,000 gallons of air per day of 24 hours, about 30 c.c. per inspiration. And the number of particles formed per head per day will be about 370,000,000. The availability for inspiration is a potential rubber particle population of 37,000 for each breath taken by each person in Britain or, 1,230 per c.c. of air breathed. In U.S.A. population being, say, 125,000,000, the equivalent number will be 133,200 per breath per person, or 4,428 per c.c. breathed—ignoring respective land areas. This tremendous potentiality does not include the large rubber-dust accumulations, or the considerable wear of other objects. Many particles will be both greater and less than 20 microns; large masses are often wrenched from solid tyres without particulation; and the 37,000 figure (Britain) per person will vary with individual habits and occupations. The breatheable maximum on windy days, will supersede quiet-day minima. Many particles, perhaps particularly due to simultaneously-formed oil and petrol products, will be pressed into road surfaces, assisting in their endowment of a pore-filling and cushioning finish. J. W. Smith (200) states generally recognized road dust causes as: (*a*) exudation of road-binding material in wet weather, and additional mud caused by friction of stones *inter se*, not held by strong, cementitious binder, and (*b*) mud

working to surface through insufficient macadam foundation. Rubber and exhaust dust must be added, even where, as J. W. Smith shows, tar spraying tends to suppress dust, though—like tar macadam—it may, in some conditions be dustier than ordinary macadam. C. H. W. Biggs (201) well explains vehicular-wheel road dust formation. An immediate probability is the vacuum cleaner principle of road cleaning.

The 37,000 inspiration figure suggests the remarkably powerful good or evil influence of a quickly-introduced new everyday dust. It may quickly be augmented by rubber-tyred trains—demonstrated on Palaiseau-Chartres branch line, July 22nd, 1931 ; the new land tyre for agricultural work, or depleted—somewhat metallically replaced—by F. Hough's iron-road invention of 50-year wear, the first public approved cast-iron road of 10 sq. yds. per ton tripedal unit system (inventor, F. Small) being laid at West Ham in August, 1931.

It is now augmented by fast increasing rubber sole use, and tremendous bicycle-tyre dust production—particularly applicable to certain cities, e.g. Oxford, where use is general. "Fillers" such as litharge, and sulphur may assist rubber dust in producing definite, general, pathological effects, possibly, along with others, initiating chemical or physiological action assisting certain widespread diseases—particularly in view of the 40% body detention. The general effects—recognized or not—must be at least considerable.

The 37,000 rubber-dust figure may be compared with that due to coal burning. The Departmental Committee on Smoke Abatement (reporting 1921) estimate fuel-waste as soot as $2 \cdot 5 \times 10^6$, and $0 \cdot 5 \times 10^6$ tons, respectively domestic and industrial, i.e. 3×10^6 tons per annum, equivalent to 3 days' national coal output, or 3×10^6 days work per annum for soot production. Practically all this contamination is avoidable in using low-temperature-carbonization-produced fuel, with parallel production of oil-fuel and motor spirit—a subsidiary particle producer. Travers (454) has also discussed the prevention of atmospheric-dust pollution. British coal consumption reached peak value of almost 220,000,000 tons in 1913—fallen in 1932 to about $1 \cdot 5 \times 10^8$ tons. With 20 micron average particle diameter (since about 50% flue gas dust is less than 20 micron (146)), assumed-spherical particle volume is $4 \cdot 1 \times 10^{-9}$ c.c. ; number approximately $2 \cdot 5 \times 10^8$ per c.c., and specific gravity being, say, $1 \cdot 4$, $1 \cdot 76 \times 10^8$

particles per gram. J. W. Mackenzie (203) showed from $5\frac{1}{2}\%$ to 11% total coal burned is stack-passed, without means of arrest and using pulverized fuel. The figure of $8 \cdot 4\%$ is deduced from those given (146) of a 12% ash pulverized fuel, 70% stack-passed (which may rise to 90%)—though but $1 \cdot 2\%$ to stack for stoker firing. Perhaps an all-round figure of 5% may be supposed to cover domestic and industrial consumption, giving 11,000,000 tons annual British waste on the peak value. *This contrasts with the* 3×10^6 *tons above,* and another estimate of 9,000,000 (9×10^6) tons.

The equivalent of 11,000,000 tons being about $1 \cdot 2 \times 10^{13}$ gram, the potential annual particle output is $2 \cdot 1 \times 10^{21}$, or 2,100,000,000,000,000,000,000, giving with the same criteria as for rubber dust, approximately $1 \cdot 3 \times 10^7$ or 13,000,000 per inspiration, or 433,000 per c.c. inspired coal-produced particles for Britain, compared with 37,000 and 1,230, respectively, for rubber dust. The contrast suggests the relative breathable importance of the two dusts—in both cases city-concentrated, but proportionately more with carbon dust. The very apparent eye-level, large-scale rubber dust production of 37,000 is more insistent than the 13,000,000 quiet, unobtrusive, overhead carbon dust production. The latter's greater insidiousness is thus underlined, and a visualization of its tremendous effects projected. A. Forward (202) suggests more physiological damage due to smoke-polluted air than to noxious items in food and water; that smoke damage is 2×10^6 dollars per annum in Chicago; that $4 \cdot 7 \times 10^{10}$ cu. ft. of air-diluted gases are emitted per day in Chicago; and that 700,000,000 tons of coal, and 147 gallons per person of petroleum, are produced and consumed per annum in U.S.A. Thus the United States have, say, 14,950,000 per inspiration, or 498,000 per c.c. inspired, coal-produced particles.

A huge proportion of coal particle production is, of course, precipitated in streets, building interiors and exteriors, never reaching lungs, but *nevertheless, producing mental* (and indirect physical) sensual effects, in addition to the direct physical breathing effect. Their seriousness is concluded from the 1921 report of the Departmental Committee on Abatement of Smoke and Noxious Vapours, suggesting serious health danger from domestic smoke, and direct increase in pulmonary and cardiac disease-deaths in proportion to smoke-fog duration and intensity. Of the huge carbon particle production in

Britain, assuming similar proportions, railway locomotives provide 6·5% ; coke production, 8·5% ; electrical generating stations, 5% ; manufacturing plants over 35% ; domestic needs, 23% ; ships about 4·1% ; gas works, 8·5% ; and collieries about 7%. Pulverized fuel used industrially, not domestically, industrial operations (where carbon particles of smokes—excluding ash—and tar are not considered) produce most particles, though this may be balanced or even reversed by the differing manner, or heights, in or at which the particles enter the atmosphere—essentially a meteorologic question. Since domestic effluent holds practically no grit its average particle-size production is likely to be much smaller than that of factory effluent, but the former is all stoker-fired.

Shaw & Owens (130) waste product figure of $2 \cdot 5 \times 10^6$ tons on an estimated annual coal consumption of 140,000,000 tons, is based on 2% or 3% factory-emitted and 5% domestic-emitted (20% to 40% of which is tar by weight). This relatively low estimate (which, however, favourably compares with the abnormally-low figure of 149½ million tons for 1932) would give a much higher particle production than 13,000,000 per inspiration based on their average size for smoke particles of 0·5 micron, as contrasted with that above taken of 20 micron. The possible limits of error are such that the totally-consumed annual coal consumption, hence not partially emitted, in certain operations, may be regarded as without significance.

If house chimneys, relatively close, average about 50 ft. height factory stacks relatively distant about 300 ft. height, considerable effects must follow such differences. Thus (146) whilst pollution decrease is but 14% by raising stacks from 300 ft. to 450 ft., a strong wind of velocity 16 miles per hour at 150 ft., will have 33·6 miles per hour at 1,500 ft. Surrounding buildings disturb air-flow to a height less than thrice building height. Streamline flow at stack heights compares with eddies at domestic chimney heights, preventing easy dispersion of particles. Such data, and other not determined, will need correlation to determine stacks or chimneys as chief pollution culprits, particularly as one city's small particles pollute other, distant cities. If German coal production is about 116,000,000 tons per annum, the pollution of Great Britain and U.S.A. is probably greatest per caput. H. B. Meller (197*a* and *c*) suggests that 20% of the U.S.A. fuel bill

is wasted, particle effluent being doubtless a large proportion. Given city figures are not, necessarily, typical of countries concerned. Thus Duisburg, Germany, with 100 tons per square mile per month pollution exceeds Liverpool (June, 1924) with 97 tons per month, and Pittsburgh (average for June) 89·7 tons per square mile. Whilst Pittsburgh in August to June, 1923–1924, had 1,304·4 tons per square mile, and London but 194·6 tons per square mile average, August to June, for 5 years, London is not an industrial city. The heaviest British deposit in 1932 was about 739 tons per square mile per annum at Ashington, whilst Pittsburgh average, 1929–1930, was 986·5 correspondingly, and for its dirtiest quarter —Woods Run—no less than 2,319 tons correspondingly. Both for Ashington and Pittsburgh figures are probably low, due to industrial depression, but—the figures supposed criteria—Pittsburgh's larger deposit is, probably, significant of geographical position, unfavourable for pollution dispersion. At the new Battersea power station coal is being consumed without smoke, dust or sulphur gas production. A train locomotive burning 4 tons on a journey may produce, say, $3·9 \times 10^{13}$, i.e. 39,000,000,000,000 particles spread over perhaps 160 miles —a distribution continually occurring day and night in multitudinous cases. Modern locos with self-cleaning front ends, void practically all ash and grit. The draught employed, large compared with factory or domestic hearth, higher ash proportion will be emitted. H. B. Meller (197*b*) states 8·05% of coal (modern locos. burning 1,500 to 15,000 lb. fuel per hour) representing 19,134 b.t.u., would be voided in cinders and sparks; whilst losses of 2·3% to 13·6% and 6·3% to 17·8% on dry coal weight dependent on coal size for burnings of 3,600 and 7,650 lb. per hour respectively, at b.t.u., cost of 7,474 to 10,482 and 10,728 to 11,037 were found on another railroad. J. R. Ashworth (522) gives valuable information —more particularly of the Manchester district—concerning suspended matter, influence of pollution on light, etc. He states that, generally, transported matter is very much greater than deposited matter, and that a relatively much greater amount of soluble matter is carried along than deposited.

The Relative Dust Content of City Air.—Carbon particle preponderance in city air is confirmed by E. E. Free's (203) New York soot particle determination, showing that 40% solid deposit did not originate in fuel—H. B. Meller (197*c*)

favouring a similar amount for Pittsburgh—never less than 96% was always unburned carbon at 17th floor level in New York, with at least 90% soot or unburned carbon particles at street level. Wind and degree of flocculation were the two great particle number variants—flocculation cause not being discovered. Wide variations, possibly covered in 2 to 3 hours, from 0·1 to 3·0 × normal were observed. Rubber, asphalt, brick, rock, horse excrement and other organic, and small glassy scales (probably from building glazed tile), as well as unburned carbon particles were found. Leather, cotton fibre, human hair or skin scale, particles were in slight amount, absence of diatoms, Tissandier spheres and soil particles being explained by possible soot immersion. Particle size varied from 2·5 to 0·5 micron (suggesting much greater numerical dust production than the 20 micron average adopted); aggregate size from 5 to 16·6 micron. Aggregate percentage was very variable—believed an original observation. A rise of 100 ft. above street level showed a 25% to 50% reduction. This suggests an analogy with Perrin's artificial atmosphere (17). If 40% deposited particles are not fuel-formed, the 13,000,000 per inspiration representing 60%, the total possible number per inspiration will be 21,600,000. This leaves 8,600,000 particles per inspiration made up from the numerous other dusts mentioned (including 37,000 rubber dust). Free found greater aggregation with greater particle number difference from street to higher level, suggesting aggregates settle more rapidly than individual particles—a practical example of Stokes' law (6). But since "effective" density of aggregates is likely to bring them within Stokes' law ambit, this distinction may be due to that between Stokes' and Cunningham's laws, referring to particles less than 0·5 micron radius. It may be compared with fog settlement figures at Cheam, January 11th, 1925—Shaw and Owens (130)—when smoke aggregates were settling at 80,000 per sq. cm. per minute. If unaggregated (the aggregate average radius was 0·4 micron) rate would be about 19,000 per sq. cm. per minute. Another fog showed that when jet dust counter count was 27,000 per c.c., only 1,200 per sq. cm. per minute were falling. On the other hand, Whytlaw-Gray and Patterson (205) have recently shown that in artificial smokes the effective radii of aggregates is likely to be similar to single particle radii. Free found erratic rain effects on settling from no soot decrease to large soot decrease.

D. R. Morris (203)—discussion—stressed the changing emphasis from country or volcanic to city dust production. This change will be more observable in newer countries. H. Kreisinger (203) considered the large street automobile vehicle smoke-dust production, whilst P. Drinker stated a well-known smoke-study fact of the disappearance of smoke in a confined space (204) that aggregation was accelerated by turbulent air motion or ionization, and that particles—especially carbon—of 0·5 to 5 micron mainly settled by aggregation. Lowell Andrew (203) pointed out that counts as high as 152,000,000 per cu. ft. (about 5,000 per c.c.) had been made with an Owens' dust counter and magnification of 1,000. Laura A. Cauble (203) referred to constant average loss of 30% visible light in New York, due to smoke pollution, with 42% on longest June sunny day, with 36% loss the following day. Comparisons were made with country immune from smoke waste, indicating the intolerable smoke burden. Colonel the Master of Sempill (535) states that atmospheric pollution may rise over Manchester, Sheffield, Huddersfield, Leeds, etc., at least 6,000 ft., and sometimes 8,500 ft. J. Aitken's haze researches (28) on Rigi Kulm, showing the less the water vapour the greater the particle number for haze production, explain these sunlight losses. For wet bulb depressions of 2 to 4; 4 to 7, 7 to 10 degrees, $1 \cdot 25 \times 10^{10}$, $1 \cdot 71 \times 10^{10}$, $2 \cdot 26 \times 10^{10}$ particles, respectively, in an air column of 1 sq. cm. cross-section, would produce complete invisibility. Further that Hochgerrak (70 miles distant) was never visible from Rigi Kulm when there were over 2,000 particles per c.c., in the air, and that if any two of factors, (*a*) visibility limit, (*b*) humidity, (*c*) particle number, were known, the third could be calculated. He showed also that air, of wet bulb depression 8 degrees, is 3·7 times clearer than that of 2 degrees depression. J. S. Owens has also shown that as haze is likely to carry mixed hygroscopic nuclei and non-hygroscopic particles, the latter will have chief causation when less, the former when greater, relative humidity obtains. Applying Aitken's relationship between air-particle content and haze, Meller (197*b*) has shown that in certain Pittsburgh winter months at 7.45 a.m., with visibility averaging 1 mile, the consequent particle population was 100,000 per c.c.; at 12.30 p.m. visibility averaging 1.6 mile, 62,500 particles per c.c. The visibility in London city, generally regarded as averaging 0·5 mile, the particle content would seem consider-

ably higher than Pittsburgh's highest, though solid matter deposited (197*c*) show comparative figures: Pittsburgh: London : : 1,304 : 180. These apparently contradictory conclusions would be harmonized if dust is retained longer in London atmosphere owing to the immensely greater traffic. They serve to emphasise the effect of traffic in intensifying and maintaining atmospheric pollution and the large dust (rather than smoke) effect. The lowest atmospheric dust layer of, say, 1·5 km. is very likely most largely determined by traffic.

Other Typical Dust Sources.—Tobacco-ash dust is produced in quantity. About 240,000,000 lbs. unmanufactured tobacco per annum enters this country. If ash produced be 33,600,000 lbs. (average 14%) excluding cigarette-paper ash, particles per inspiration per person are, taking same constants, 25,500 (even if the high specific gravity = 1 be assumed). This dust source from 2·4 lbs. per head in 1914 increased to 3·4 lbs. in 1927, 880 cigarettes per head of population in the United Kingdom being consumed in 1926. Whilst ash-tray use will largely restrict atmospheric dissemination, somewhat enhanced by rain water dissolution, a large tobacco-ash quota will supplement breathable-dust population.

In cities about 1900, dust population would be substantially identical with the coal-fuel and turnpike-road inception period, chiefly comprising carbon, road dust, and horse-excrement particles, in addition to micro-organisms and the more natural components. Now, about 35 years later, carbon, rubber, and tobacco-ash particles will be important constituents. A significant, if little-suspected, change. A country walk does not now involve a return miller-like appearance. The erstwhile rich, limestone-dust road deposit is now discouraged—practically non-existent.

Imported motor spirit being about 955,000,000 gallon per annum into the United Kingdom, including home production, 1,000,000,000 gallons probably represents total consumption. If average too-richness of petrol mixture used is, say, 10%, this proportion may be regarded as burned to fine particles only, i.e. 100,000,000 gallons, or $4{\cdot}55 \times 10^{11}$ c.c. If practically all particulated, 7×10^5, or 700,000 particles per inspiration (hypothetical 20-micron diameter), will be formed. A very large, if much smaller than coal-produced, figure. Its effectiveness for harm may be a still smaller proportion, for these particles (*a*) have small distance to settle, and (*b*) do not

necessarily pass breathing level in doing so. The reverse applies to coal-produced particles, and they have also much greater diffusion opportunity. A recent suggestion to transfer exhausts to car-roof level would undesirably take exhaust gases ultra breathing level. Probably loaded with adsorbed carbon monoxide and dioxide, and steam, a huge number will be pressed into road surfaces (along with rubber dust), and, also conjointly, also largely raised into the air by constant vehicular streams. Completely added in, say, the last 30 years, the possible adsorbed carbon monoxide is of tremendous importance. Where not oxidized to the dioxide, a steady poison production is inevitable. Less diffusible than the still-unadsorbed carbon monoxide, its retention will be much longer, its danger consequently much more cumulative—adsorbed films, even with specialized precautions, being difficult of removal. Unfortunately, also, the rapidly increasing aircraft petrol use, means a further dust population—thus carbon monoxide-charged, increasingly introduced well above breathing level. As the stratosphere is being studied as a possible pressure-free air route, the future may see huge dust additions to that region. Not yet general, when it is so, carbon monoxide—adsorbed or unadsorbed—will augment at breathing level that from cars, becoming unpleasantly effective. The more ephemeral, because more diffusible, unadsorbed carbon monoxide was referred to by Sir William I. De Courcy Wheeler at the British Medical Association meeting in Dublin on 28th July, 1933, who stated: "The blood of traffic policemen has been found to be charged with carbon monoxide at a high concentration; the blood of those who constantly motor in the city must be similarly polluted." This emphasizes the danger from carbon monoxide-charged dust particles. The definite tendency of fine particles to entrain gases—a tendency increasing with particle-size decrease—may be gathered from the fact that a 50 kgm. package of 0·15 micron zinc oxide is larger than a 50 kgm. 0·8 micron zinc oxide package (196). C. B. Maits (471) has found that, in the Pittsburgh vehicular tunnels, the carbon monoxide was often excessive, the traffic during peak periods sometimes reaching 3,400 cars per hour, whilst 73 British local authorities have tested monoxide amount in foggy weather at traffic centres (531).

The reality of the danger of the exhaust dust particles

themselves, apart from possible adsorbed films, is shown by the work of J. T. Dunn and H. C. L. Bloxam (207), who analysed grasses along much motor-used roadsides, and invariably found small quantities of lead and copper, lead being found on the leeward, but not on the windward, side. Of two cars both using lead tetrethyl motor spirit, one contained 82·7% lead sulphate, and the other 31·06%, in valve and cylinder deposit, respectively. Figures for the dust, thus probably conveyed from car exhausts, averaged 6·5 parts per million of lead, in the grasses. It may be noted that the grasses were also covered with other dusts, whilst a 4 square foot area soot gauge collected 12·36 gram of solid suspended matter in March, 1932, in Newcastle-on-Tyne. Non-carbonised petrol excess will be offset by carbonised engine oil emitted, which, often containing also rubber and other road dusts, will be likewise carbonised. This reality is suggested by the statement (208): "Road dust and sand, which work into the engine, play havoc with the lubricating value of the oil. In an air space the size of a hen's egg, there are a million dust particles. The greater part of this dust is blown out through the exhaust, but some particles adhere to the combustion chamber surfaces. These mix with the oil and help to form hard carbon. Some of the dust gets down into the oil in the crank case, and in time this oil becomes gritty and acts as a grinding compound instead of as a lubricant." The huge, daily, internal combustion engine itineration burns and destroys a huge amount of normal air dust, smoke particles, etc., concluding the combustion omitted by the fuel fires in their formation. If petrol air consumption per gallon is 1,500 cubic feet, i.e. 40,000,000 c.c., and air particle content 30,000 per c.c., $1{\cdot}2 \times 10^{12}$ particles per gallon will be heated. Some will burn partially; others completely; others show little effect. Total particles destroyed, offsetting those created by unconsumed petrol, cannot therefore be stated.

The numerous pressed-in road surface particles only temporarily retard dust population growth, since road surfaces wear. A compensating process, later releasing particles previously pressed in, is set up, witnessed by frequent road repair necessity. Pressed-in particle release will be augmented by huge new particle formation as the road surface itself is worn down. Whilst some engineers prefer the road-making sand, pebbles, or gravel initially fine-dust free, since crushed

in use, others start with very fine dust addition as a filler. To lime coat sand, particularly that from crushed sandstone, fine dust removal may be a necessity. J. MacAdam relied on use to provide the necessary fine material—A. B. Searle (209). In any case, a large proportion of fine material is obviously available for addition to released pressed-in dust. This is reflected in E. E. Free's work (203). Repairing or remaking roads adds large dust amounts to the air by sieving sands, mixing with fine dust, concrete mixing, and numerous other operations. The continuingly greater pressure on roads, with advancing car manufacture, increases dust production. Meller (197*b*) finds mortar 0·3 in. deep disintegrated from many older buildings, and softened in other cases to 0·4 in. depth. Myriads of struck matches are producing dust at striking point, by luminous flame, and from charred remnants. Replacing automatic lighters have smoky flames. Street gas lamps doubtless produce fine dust, for the frequent necessity of cleaning new reflectors cannot all be oxidation-caused. Even the increasing "powdering" and "making-up" will add its quota. Odoriferants, malodorous and pleasant, such as perfumes (110) probably produce their effects through exceedingly fine particulation, and the wide prevalence of such particulation extending to nuclei in gasoline, benzol, etc., is shown by Barus (537). Wolski and Kenrick (369) have shown distilled water to contain 20,000 motes per c.c. Like road engineering, building will add inorganic dusts, e.g. lime, cement, sand and soil. Very large amounts of base metal, e.g. steel-track rail dusts, are added. Any much-used tram-track—especially at crossings—proves this. It implies a similar dust production from wheels and brakes, and from sand to prevent skidding—friction-produced dust. The fine siliceous dust mixed, doubtless, with iron dust, may sometimes be seen as fine, grey powder in the track hollow. Its high specific gravity will give it, normally, low circulation. Similar, probably, finer metal dust may sometimes be scented when brakes are rapidly applied to a train. Sir R. Hadfield (114) states pig iron production in 1796 was 125,000; in 1819–1824, 450,000 tons per annum. In 1929 world steel production was 120,000,000 tons, about 146 lb. per annum per head. He states (115) that corrosion and wear and tear cost from £500,000,000 to £700,000,000 per annum, 67,000,000 tons (exceeding by 19,000,000 tons that year's production) being wasted in 1932. The chemical cor-

rosion product of this metal is more amenable to disintegration than the metal, and will mostly form dust. Wear and tear of the metal—apart from breakage—will produce immense dust. Meller (197*b*) considers corrosion increase in smoky districts due to galvanic action consequent on electro-negative carbon films lying on electro-positive metal surfaces in atmospheric acid and water presence. Any substance promoting electrolytic action will assist corrosion, and rust-concealed pitting is also due to ferric oxide-iron formation. Painting and renovation of metals in smoky atmospheres is doubled, and metals like zinc, copper and bronze corrode and form dusts. When about 60 lb. of sulphuric acid per ton of fuel fired is formed, this is not surprising. Added to the tremendous iron-dust deposit in appropriate manufacturing regions, awaiting wind removal, the air must be well charged. Railway station roofs often so badly corrode—under engine smoke action, whose particles will probably carry adsorbed sulphur gases—they must often be completely replaced. Iron-tyre wear, edged-tool grinding and wear, railway line and wheel wear, with a hundred and one other sources, will supplement the huge carbon particle product formed in metal manufacture. Where ganister is mined, granite sawn, or quartz crushed for silica brick manufacture, a floating dust production will supplement that inhaled by workmen or deposited. Here, again, wear-produced metal dust will augment the siliceous—so great with some crushing machine manganese steel jaws that detachable bars, to avoid scrapping their framework, are now supplied (Carnegie: Patent 28,108). Quarrying and blasting operations produce rock dust, siliceous or otherwise, in large amount. The 32,000 tons blasted at Buxton in the presence of H.R.H. Duke of York in May, 1933, is, doubtless, exceptionally large. Much quarried dust—particularly with narrow strata—will be clayey, of similar particle size to city smokes, viz. 5 to 0·1 micron diameter, forming a rural counterpart. And such fine clay particles may be included in road-making materials.

Vegetation and mould spores form an important constituent, seasonal—like carbon particles—though not coincident as to period. Rubber dust, again, will be seasonal, whilst probably tobacco ash and metallic dusts will not. That is seasonal, or not, as regards maximum formation at given annual periods. J. T. Dunn and H. C. L. Bloxam (207) found dusts of lead,

copper, zinc and arsenic seasonal. The proportions in different places in Newcastle-on-Tyne, and in flue dusts, of lead, copper and zinc compounds, being often larger than the proportions in the pyrites of the coals bearing such metals, suggests extraneous industrial sources, and the determinations of C. H. Manley in Leeds suggest such extraneous sources, e.g. smelting, for that city. From one soot gauge in Newcastle, 2·22, 0·27, and 0·96 tons per square mile of lead, copper and zinc were respectively found, and the serious possibility of lead poisoning to human beings and animals due to such dispersed metallic dusts is discussed.

Refuse Dusts.—Such sources as above outlined of air dust production are also those, on settlement, of street dust formation, in whose removal by numerous workers an appreciable proportion is returned to the air. Seeming more prevalent in warm weather, special slaking means are commonly taken. The annual British refuse dust amount is about 11,000,000 tons—strangely coincident with the estimated smoke dusts produced, with a very real, though not arithmetically-demonstrable, connection. The 1930–1931 national bill for street cleansing was £3,371,607, ratio of cost to weight varying with locality. The historical persistence of extensive refuse dust is suggested by the finding at Ur by C. L. Woolley of a rubbish heap in its centre. There throughout its history, it gave evidence of periodic depletion for the structure of terraces on which to erect houses. Private refuse dusts both supply and supplement the public proportion. Its removal from house to receptacle, from receptacle to vehicle, almost always entails an addition to floating dust, inevitable despite modern vehicles with swing lids, sacking, or curved hoods, reducing dust escape. Even slight breeze lifts dusts in transference from house to vehicle—ash dust or swept-interior dust largely—the latter of high bacterial content, reduced by sunlight and fresh air bactericidal action. "Keep your bin dry. Burn more refuse, and reduce your rates" adorns many refuse vehicles. An invitation to increase the already-sufficient staubosphere. For, whilst showing other unpleasant effects, wetting will certainly reduce dust dispersion. And burning refuse will increase dust production. House refuse includes cinders, breeze, rubbish, and filth, etc. (211). An unalluring mixture for atmospheric flotation. Hoffman, in 1909, studied dust raised in scavenging. Cinders, breeze, etc., are often used

for public cinder paths, there providing, until trodden in, a further dust source. Cheap fuel areas are industrial areas, hence greater refuse-dust production accompanies greater general dust population, for cheap fuel implies more refuse and more dust. Thus like produces like. Adams (212) states 5·2 cwt. per head per annum for London house refuse. It may be about 14 to 23 cwt. per day per 100 population in general. Size range is not fully known. The cleaner fraction is partially used by clarification contractors, who thoroughly pulverize and calcine, then sell it, for ever-increasing industrial purposes. Local authorities, in modern practice, salve refuse by destructor burning. Salvaged clinker averages 30% of refuse. Salvage by pulverization—further dust production—producing powdered black mould, a fertilizer, is also practised. This will be partly available for air dispersion.

Wire brush or sand blast stonework cleaning, since adding stone to soot dust, must be regarded as harmful in general effect, though there is æsthetic compensation.

Country and City Dusts.—Variation between country and city dusts will largely depend on the proximity of the sources. Country over, say, 70 miles from the nearest upwind city, with wind at 10 miles per hour, will receive no particles over 10 micron diameter (146), and at over 17 to 20 miles, none over 20 micron. But 5-micron diameter particles may settle up to 276 miles away, whilst the immense range of over 8,000 miles for 0·5-micron particles hardly now obtrudes. Agglomeration will reduce the range of these effects, and E. E. Free (203) has shown considerable agglomeration. Cohen and Ruston (213) estimate that of 35,000 tons of soot from 1,500,000 tons of coal burned in Leeds, 31,480 tons is carried away, supplemented eventually by 3,472 tons only temporarily deposited. No country locality in populous British regions will be 276 miles from the nearest large smoke centre, the majority being relatively near. All country districts will suffer city dust effects, therefore, despite prevailing wind effects, temporarily, in a degree varying with agglomeration, distance from the polluting source, and position with regard to prevailing winds. Country districts will produce relatively little dust, consisting, except road dusts, of soil and manure dust raised by agricultural operations, or subsequent wind raising, vegetable spore dusts and seeds, and village and hamlet refuse dusts. Generally, country districts must be city-dominated, the degree

depending on relative height and geographical position of the given country district and the polluting city. In the west, particularly near hills, heavier rainfall will assist agglomeration in reducing particular particle travel, more than the less rainfall of eastern low-lying districts. Despite that, as shown in New York, some rains are very effective, others ineffective, in removing atmospheric dust. Whilst the deposition of insoluble dusts is rejected by Shaw and Owens (130), Cohen and Ruston (213) state that clouds carry soot particles which are deposited by rain, and that, in the Lake district, characteristic black scums have been observed on sheets of water and on hill snows which left soot particles on the grass. Such deposits are deposited far from their source, as are salt crystals from the Irish Channel found in Leeds, 60 miles away. Their observations that solid impurities in Leeds rain decreased to 50% one mile north of city centre to about 16% at 2·5 miles distance, and that at 3 miles north-east they are only 5% of the rainfall deposit in the industrial districts, seem directly to oppose Shaw and Owens' conclusion (130). Country districts may be very high compared with the contaminating city, even allowing for 300-ft. stacks, and even the smallest particles, with a horizontal carrying wind, may drive to the rising ground quickly, without regard to their normal travel. Vice versa, particles may be projected much further than their normal travel due to greater settling depth dependent on land contours. Whilst high country districts may themselves project through the lower dust region, they often have a rugged, moorland, sandy condition, and have scanty soil and projecting rocks. Disintegration of their surfaces is more rapid, since more subject to weathering than low-lying soil-covered districts of the more normal dusts. They will have relatively large weathered dust populations of their own—often siliceous—which would probably supersede any city dusts there arriving. Their exposure will cause them to suffer greater wind dust removal. The combined effect explains their clearer, healthier atmosphere, indicating by contrast the unfortunate health effects of our dust atmosphere. A typical site is Ringinglow near Sheffield, high on the millstone grit, a clear-aired vantage ground (certainly on the west) of the ever-denser smoke pall towards and beyond the city. Sometimes, the Hope Valley and Sheffield filled with fog, this intervening high land is perfectly clear. A similar district lies between Fordingbridge

and Cadnam (New Forest), though without a large adjoining city. In both cases a large local quick-weathered dust potentiality is quickly wind removed. If city carbon particles are not acidic, they will have a beneficial effect on the country soils where settling, somewhat counterbalancing the polluted atmosphere, and likely to increase with increasing distance due to the greater opportunity of acid removal by rain. This is confirmed by complaints which often arise concerning bad acidic effects on soils near factories.

The contamination difference between city and country air is shown by comparing data for same-sized houses in Leeds and country—Cohen and Ruston (213). Cleaning soap is 50% ; labour about 25% ; window cleaning, 25% ; curtains, 4%; and domestic assistance 66%, respectively, less in the country. E. O. Simon and M. Fitzgerald (214) estimate that household washing—were Manchester as clean as Harrogate—would be reduced by £250,000 per annum. Meller (197*b*) considers 10 to 20 dollars per head per annum is the smoke toll in a smoky city.

(2) *External Incidental Circumstances.—Familiar Effects*: The generalized atmospheric pollution attack now gathering force, after constant preliminary study in Great Britain and the United States since 1912 to 1914 shows that dust (as such), hitherto almost completely neglected, will require at least equal study to smoke (as such). Thus Meller (197*c*) suggests that existing legal measures, not touching dust and deleterious gases, are utterly inadequate, that various American engineering societies are likely shortly to formulate comprehensive plans for controlling dust-producing stacks, and that dense smoke is responsible for but a small percentage of solid matter precipitated. His institute (Mellon Institute of Industrial Research—Air Pollution—in charge of W. A. Hamor) intends broadened enquiries, including the effects of solids on fog formation, etc. He regards, amongst the necessities of a hygienically clean atmosphere (197*a*), control of automobile exhausts, reduction of bare spaces where dirt may be picked up, street and roof cleaning methods, and care of railroad rights-of-way to minimise dust raised and wind carried.

The most widespread external incidence is probably that in which dusts attach themselves to all objects—animate or inanimate. Use breeds such familiarity therewith that thought must precede realization that, without exception, exposed

surfaces are submitted to a continuous dust particle drive. Probably one of the most classic, continuous and grievous effects of erosion, due minimally to physico-chemical agency, maximally to time, within the ambit of civilized man, is that everywhere confronting, on the fabric of the Oxford Colleges.

The tremendous wear, by steady attrition of blown dusts on all kinds of materials of even the hardest consistency is well instanced by carved lettering obliteration on, e.g. tombstones. Such provides a reference standard, gloomy withal, in numerous churchyards, of the steady powerful abrading effect of circulating city dusts. It will be assisted by weathering accelerating dust augmentation of the staubosphere. Acidic fumes, e.g. sulphur dioxide and trioxide, constantly pumped into city atmospheres is a specialized and ever-increasing dust-forming erosion. Thus Sir F. Baines, at the National Smoke Abatement Society Meeting, London, on July 14th, 1933, called it " the destructive canker of the age," stated that House of Commons stonework first survey disclosed 35 tons of loose or broken weathered material; that finest slate from Chelsea Hospital roof might be pierced with the finger; that atmospheric pollution in the last 25 years cost at least £55,000,000; that all legislation had failed to tackle sulphur gases—the most destructive agent; readings of history in all national monuments will, probably, be rendered unintelligible; yellow discolouration is already ruining the Cavell monument, though cleaned six times a year; that on many ancient buildings and monuments " that mark (the original craftman's) has remained untouched for centuries, and it has been left to our industrial age to ruin it." G. M. B. Dobson's air-sulphur gas studies near Oxford seem to show pollution spread from industrial north Oxford (528).

Nevertheless, London is not an industrial city, where free and particle-adsorbed acidic fumes are probably more preponderant. Information on stone preservation is found in the Report of the Stone Preservation Committee, H.M. Stationery Office, 1927. W. Palmer Wynne (215) showed that in Sheffield in November, 1914, to January, 1915, the ratio of sunshine of the University neighbourhood to Attercliffe was 167 : 99; whilst Fowler (216) showed a ratio between Davyhulme Sewage Works and Manchester College of Technology of 2·36 : 1. In Pittsburgh, Pa., in 1912, the smoke bill was about 10 million dollars (217), representing a deposit of 1,031

tons per square mile; in London, 1924, 288 tons per square mile, costing £8,400,000—over greater London—Shaw and Owens (130); and in Manchester (218) in 1918, £750,000 per annum. The practical potency of these acidic fumes is witnessed by the corrosion of multitubular oil-fired boiler tubes, due to acidic flue dust combining with condensed moisture. The acid formed has, in some cases, quickly corroded boiler tubes to paper thinness, so that they buckled under their own weight on lifting.

Periodical cleaning or renewal of almost all surfaces is necessary—the window-cleaner's bucket water exemplifies the necessity. Wood surfaces must either be covered or be burnt over. Meller (197*b*) advances useful data concerning painted surface dust effects. Thus the washings (with distilled water and small sponges) of test panels of paints in the U.S.A. contained 1·5% to 4% carbon, 1% to 8% iron oxide, and 2% to 9% of acid-insoluble material from the surface deposit and interior paint-skin film—all from the air. New paint coats were attacked underneath by the deposit on the old underlying coat, as well as by fresh deposits, promoting quick appearance deterioration and shortened life. A concensus of opinion of master painters showed repainting necessary in from 1 to 3 years in smoky cities; after 5 years for first repainting, and then at 7-year intervals for non-smoky districts. Concomitant deterioration also arises, e.g. the earlier necessity to burn off old paint coats when repainting. Interior damage is proportionate with regard to decorative papers, fabrics, woodwork and other articles of value.

All walking individuals are the butt of a never-ceasing, hardly-realized (since mostly invisible) fine dust drive, permeating clothing pores, some to the underclothing and skin. Dress reformers may, therefore, wear totally washable clothing. Vast dust population is removed in discarded clothing, and permanently enshrined under fresh paint coats. New clothing, a colloid structure of solid dispersion medium and gaseous disperse phase, becomes one of solid dispersion medium and solid disperse phase, as old, dust-riddled clothing. All carry a considerable dust population of all conceivable varieties; some shed outdoors (by exchange for new dust); others indoors, by brushing and contact. This emphasizes the largely unrecognized saturation of everything with dust. Recollecting that, in general, exposed hands, face and neck will be less

efficient dust retainers than clothing surfaces, that their area is relatively insignificant, and that a few hours' exposure before washing provides a considerable dust dispersion in washing water, the vast amount of clothing-captured dust after a few months will be astounding. Generally and paradoxically laundry and private activities are directed to clothing relatively dust protected. Were heavier, outer dust deposits as often attacked, laundries and detergents generally would vastly increase.

General Effects.—The wings of birds and insects—whose numbers vary from one or two at sunrise to about 70 in the early afternoon, declining to one or two at sunset per cubic metre, in France (A. Bonnet)—tend to keep circulating much dust which would otherwise settle. The cold, high winds from the Gobi Desert have, in a few hours, filled trenches with sand in recent Sino-Japanese fighting at Tashintala, and in the Great War Egyptian campaign, sand trenches were notoriously difficult to keep clear. In their Walvis Bay flight, February, 1933, Gayford and Nicholetts ran into the dust-laden fog of the Harmattan haze in Nigeria, the sand probably rendering unserviceable their automatic control. The large amounts of fine sand which must be carried up by dust devils over deserts is witnessed by the wings of medium-sized aeroplanes requiring to stand 8-ton strains due to the fierce upward current. The two sides of a cruising aeroplane are often electrically charged to a high potential, a pilot being unseated by shock on simultaneously touching both sides. Such charge may be due to the staubosphere through which aeroplanes continuously plough. "Desert Cloud," a well-known airwoman's airplane name, seems to suggest dust. In the April, 1933, motor race round Italy, the track through the Dolomite Alps was expected to provide encirclement of competitors by enormous dust clouds. In parts of India in April dust lies inches thick over the roads, and a heathen rite is the eating of some dust or gutter refuse as a deitary propitiation. In May, 1933, Lindbergh encountered a sandstorm in New Mexico whilst flying, and was missing, due to a forced landing after two and a half hours' battling. On the second flight—Houston–Mount Everest Expedition, spring, 1933–April 19th—striking photographs of the highest earth surface dust cloud—the ice-plume of Everest (see Frontispiece)—were obtained by A. L. Fisher (219) ; one from south-west shows the several-

mile long particle plume stretching eastwards. L. V. S. Blacker (*Times*, March 9th, 1934) states that in passing through the famous plume " that awesome, miles-long white streamer which men see and marvel at 200 miles away, huge flakes of ice rattled round the cockpit with such force as to break one of its windows." The ice-plume was an identification aid, its magnetic bearing being exactly known, and its length giving an exact idea of wind velocity from the summit of Everest—L. V. Stewart Blacker (219). A powerful wind —probably Katabatic—caused the aeroplane a 2,000 ft. height loss in a few seconds. Such a wind would presumably be charged with snow dust and fine ice spicules such as fill polar air, for two airplanes on April 3rd could not perform landmark observations because of the heavy dust haze around Everest up to a height of 19,000 ft. H. Ruttledge (220) prefers a strong theory that above 25,000 ft. " the only clearing agent is the north wind," the sun having little or no melting power (*Daily Telegraph*, June, 30th, 1933). The immense amounts of powdered snow raised, with very restricted visibility, in sudden violent winds against which a man cannot stand, can be imagined. Hail, of less restricted operation, though probably causing greater damage than sand, it is suggested by Alexander (110) might be restricted in size by the possible artificial provision of more nuclei for unit formation. Their intensity and danger must be similar to that of sandstorms, the dust being vastly different. In Ulm's flight from Australia to England, commenced in June, 1933, fears of his trapping by the fiercest remembered sandstorm at Basra were entertained. Atmospheric dust would seem to be a particular bugbear of airmen, indicating its wide and important prevalence, likely to increase.

Numerous black streaks show rain dust deposits against a still-white background on two new midland city buildings. A plentiful supply of grey dust is swept every other day from between railings and wall of a public midland city building, whilst the 48 steps of a large public library yield about 2 cwt. of dust per annum. On a day, and in a location of good visibility for miles, the distinct background was completely obscured by normal small mat shaking. Immense autumn dead leaf accumulation produces large dust addition, whether by burning or foot or wind trituration. In Lincolnshire in 1897, a whirlwind covered an area of 5,000 acres thinly with

deposited plants, some from sand dunes 25 miles or over away (Woodruffe-Peacock). Wall, tree, telegraph pole, and all other surfaces will lose dust under the dust bombardment. Outside church lamps, with bulb totally glass-enclosed, had a thick, black dust deposit in the globe base and a light sandy one from rains on its exterior. Heavy rain may raise dust (partly wetted) at least 18 ins. over loose soil surface. Rubbish is constantly burned by gardeners—often to keep vegetation warm by preventing radiation—farmers and householders, producing smoke particles and ash dust. The Vaalpens (dusty bellies), nomads of the Transvaal, were named so by the Boers, due to their dusty appearance from ground crawling when game stalking. Numerous disastrous property fires—genuine or spurious—create much dust and smoke. Normally visible dust is often added to city atmospheres without detection. Ascending basement steps, a luff of wind happened to sweep others, with one's eye at their level. A thin but distinct dust cloud, projecting 5 yards, only visible from that level, was raised from these exemplarily clean steps. Amassed experience has led to special dust-excluding means in watches, "dust" covers for books, "dust" caps and coats for wear, and small black spots sometimes seen on new paper surfaces may prove to be rolled-in dust collections. The mysterious transparent black and green particles of doubtful origin observed by Shaw and Owens (130), were probably the elliptic or "hour-glass" gas pore walls discharged incandescent in lava dust from volcanoes, as intermittent occurrence would be explained by successive round-the-world journeys. The small glass-like particles regarded by E. E. Free (203) as from building tiles may have had volcanic origin. A 5-in. diameter depressed grate on a midland suburban pavement lodged considerable yellow, gritty dust up to pavement level. A foot, probably, had caught this, spreading—superposed on normal dust pavement—a comet's tail. Many similar very dusty pavements and grates were in this city due, as an addition to the normal dust, of special sandy dust produced from road sprinkling gravel (plentiful gravel supplies being a feature of the local river). An 18-in. road band near either pavement was formed by about ⅜-in. gravel on the fairly traffic free road. Busier streets produced correspondingly worse dust effects, from practically dust-free gravel, disintegrated by traffic to fine, readily-raised dusts. In a northern town, about ½-in. units on

a by-road were ground to fine powder in less than a month, and had to be removed owing to the general vast dust cloud nuisance. Such dust will also act as a wheel-grinding compound in situ. In a city centre, on a public building railing ledge, is a thick light-coloured dust deposit. Exceedingly fine, it falls in clots when moved, smudging the finger. It is undesirable, road-manufactured siliceous dust, at eye-level height. The railings themselves are black with normal city dust predeposited. The incidental appearance advantage of substituting light-coloured for black dust environment may be completely discounted in view of siliceous dust danger. The tipping of coal, coke and other dusty products largely augments city staubospheres. Only a fundamental change in industrial practice can nullify black dust production.

Relative City Dusts.—When meteorological conditions have favoured steady dust settling for some days, thick layers of black dust settle on some industrial city pavements—often near large railway stations. Numerous pedestrians make such deposits discontinuous in a mosaic effect of an endless succession of obtuse-angled arrow heads, suggesting the pressure line of the ball of the foot. In a few hours, weather changing, such a dust load may be swept up for breathing, or into inaccessible corners. Environment modifies a city's dusts, and dusts deposited in rivers by natural process may be directly returned to an adjoining city atmosphere by artificial means. City health balance may be greatly affected thereby. For where, for example, silica dust is produced largely, certain industrial diseases will be selectively encouraged, in addition to mouth, throat, lung and general disease—particularly in children—from road dusts, whereas equally harmful dust selected in another city may be absent. Health deterioration may be similar, from different causes. "Remove dust . . ." on a well-known boot polish packing is pregnant with significance. In cleaning Britannia on Somerset House in May, 1933, a blowpipe was used to remove as much accumulated dust as possible. In refacing stonework which erosion has denuded to dust, workmen wear respirators to prevent dust breathing from high speed drilling. A dust episode in three stages! F. Hatch mentions dust exhausts on stone-surfacing machines, indicating how exhaust ventilation has been recently adapted to stone cutting. A railway station platform of approximate area 1,000 square yards fills a large hand-cart with platform

dust each day, principally due to passengers' footwear, though locomotive smoke and dust contributes. Dust deposits behind roof projections are witnessed by black rainflow lines—more particularly on tiles. This effect is very noticeable on the photographed dome of St. Peter's in Rome. In diffused light in railway stations and similar places, ordinary sunbeam motes numerous in the cleanest districts are noted as numerically insignificant compared with the much finer particles filling the intervening space. These finer visible staubosphere particles may be watched scintillating in intertwining streams as first one, then another, slight air current threads them. They appear *choc-a-bloc*, but when the light reverts to general (less) intensity, they fall from vision, their important presence becoming ignored and forgotten. Their effects—hardly generally suspected—are fogs which paralyse industrial centres, delay traffic, and create health and business nuisance, when atmospheric inversion occurs. Stoke-on-Trent—a very foggy place (531)—had 126 days smoke haze, October to March, 1931–1932. Smuts and harder particles often strike the face, proximity to traffic introducing them to mouth, nostrils and eyes, and gutters containing heaps of fine heterogeneous dusts—strangely tolerated, when their content is known—form an undesirable reserve. Canine excrement dust—at the level of the cesspool era—must be enormous. Organisms, at once most important and most delicate, are most amenable to them. For infant breathing level is several feet lower than adult. "Out of sight, out of mind" has particularly strong force with regard to dusts, any object "gone to dust" being regarded as beneath serious human consideration. Unfortunately, the detachment is one-sided. Dust—personified—is very interested in humanity.

Dust and Crime.—H. T. F. Rhodes (222) expatiates on the vital importance of evidence supplied by dust in certain murder cases, and (223) refers to the indispensability of "occupation dust" knowledge for projected police study. The basis of the immense data of "finger print" collections is largely fine dust, and H. Brose and C. G. Winson at Nottingham have invented the use of fine anthracene or phosphorescent zinc sulphide dust for sprinkling on finger prints on highly-coloured articles for crime detection by photography, dust previously used giving blurred images on bright colours. The new dust is exposed to dark ultra-violet rays which it retains. The

popular aspect of this dust incidence is shown in " Dr. Thorndyke : His Famous Cases " (224). Gritty dusts are criminally used by injection into machinery, and pungent dusts in personal defacement. Dust thus caused a world-wide stir in its recent alleged use in Russia.

Other Dust Effects.—When locomotive smoke flow is directly over the train, dust often beats a steady tattoo on carriage roofs, and large amounts of coal dusts are undoubtedly dispersed from rapidly-moving engine tenders. Trees and leaf surfaces are smothered with black dust in many districts. Stomata are clogged, growth stunted, flowers have a dirty, bedraggled, besmutted appearance. Cohen and Ruston (213) give much information. Wear and tear dust, of slow formation, are considerable. In London, and less in lesser cities, continual razing of large building blocks adds dusts from interiors and exteriors to those formed by razing. Pavement wear provides much dust, the irregular and decrepit nature of some pavements under foot action with reflex action on rubber and leather soles—dust producing—being often conspicuous. Kerbstone centres are seen 1 to 2 ins. below the original level, forming deep and dangerous foot traps. A few such stones will have produced many million siliceous particles. Large stones on walls under trees have been noted with large cup-like hollows, carved by persistent water-dripping. The power of wind in driving city dusts is suggested by that up to 4,340 lbs. pressure, on any face of the Empire State Building, 1,048 ft. high, whose consequent swaying motion may have a 4-second period in strong wind.

Sugary liquids will not readily ferment in but few places—temperature conditions being suitable—due to the smallness and ease of transportation of the organisms—S. Miall (225). Such organisms are an important dust component. Another instance of their propagation may be the water fermentation of flax bast, called " retting," to dislodge wood from the linen fibre. Rain drop deposits of dust may often be noticed on clean dark-coloured objects, e.g. car bodies and gate posts. In April, 1933, the Imperial Airways liner " Hanno " had to make a forced landing at Jubail, Arabia, due to a sandstorm. A public bridge over an industrial railway station has long streaks and balls (1 cm. diameter) of agglomerated soot hanging from sides and top, giving a good idea of locomotive smoke production. A modern double-tier bus, in drawing up slowly

at a quite "clean" curb, will provide a huge dust dispersion as high as itself for passengers to pass through. A large modern six-wheeled lorry, loaded and moving at 6 m.p.h. along a mid-city road, will raise a house-high dust dispersion. At the base of metal railings fixed in stone considerable rust dust deposits are often found, often so fine that rain forces it into the stone pores, producing a permanent reddish tinge even on new buildings. "Sun-stint" producing pallor, anæmia, and rickets in children, referred to by H. A. des Voeux (226) is largely due to dust-charged atmospheres (*cf.* L. A. Cauble (203)). W. N. Shaw (58) discusses the effect of the smoke of great cities on sunshine records compared with country sunshine incidence. He shows 37% sunshine loss in the London area, and even 10% at Kew. Of these losses, that of the ultra-violet radiation will be proportionately greater than that of other wavelengths, according to Rayleigh (25).

(3) *Internal Essential Circumstances.*—These, mostly domestic, will add to Class (4) next considered, in common with external dusts. The most general dust in this class may be coal dust, for every lump has an adhering film, and its importance has produced special marketing conditions in washed and cleaned coals, "coaltainers," etc. Many specifically use coal dust for enclosed stove firing. Many brands of soap and scouring powders now exist, but culinary dusts probably form the most numerous dust class. Some of the most general are flours, baking powder, cocoa, sugars, salt, pepper, mustard, etc. Disinfectants and tooth cleaners may be in powder form. According to A. E. Munby (498), the importance of dust exclusion in laboratories is sometimes met by porous plugs in openings, sometimes by raised beads on frames and a corresponding groove on doors or lids which close against them.

(4) *Internal Incidental Circumstances.*—Interior spaces, darker, warmer, less-oxygenated than exterior ones, contain much more bacteria—regarded as small dust particles. Bacterial dust will increase in proportion with others. Space confinement and ventilation-lack will cause interiors to have relatively heavy dust content, increasing with human occupation, by being raised from carpets, chairs, etc. The prefiltering of interior air, e.g. as in Buckingham Palace picture gallery, tends to produce stuffiness, and since the finest dust is the most undesirable, "stuffiness" is likely to increase with

its detention. A proportion of that raised settles on all interior objects, projecting surfaces and ledges, etc., rendering necessary the inevitable spring cleaning, and producing much work for decorators and laundrymen, particularly where in industrial districts the external dust migration is marked. Dust " webs " are well-known phenomena in empty houses—sometimes in occupied ones. Reference to the dust trap between cupboard tops and ceilings was made by Lady Emmott at a National Association of Building Societies Meeting on June 9th, 1933. Floor coverings are the worst domestic dust containers, for their otherwise desirably-soft, pliant nature makes them ideal pressed-in dust depositories.

Street-dust is introduced whenever outside footwear is retained, and the better the covering the more readily it cleans dust from footwear. A modern-type vacuum cleaner extracted 20 oz. av., of fine, greyish-black dust forming finely-divided fluff with fine textile dust from a very clean house. The suction—sufficient to lift an adult person—developed by many vacuum-cleaner fans, is exceedingly searching. Some are now being fitted with dirt-finders—lamps to illuminate dark, dust-ridden, corners. Interior dust may be added by sootfalls, whilst ash dust is always somewhat disseminated from solid fuels. Coarse interior dust fractions differ in different districts, in some obviously all sandy or inorganic, in others swathed in smoke palls, almost all carbonaceous, whilst city outskirt buildings often yield semi-sandy, semi-carbonaceous dust.

Very distinct thermal precipitation signs are often seen in interiors, the selective black or dirty patches forming on relatively cold surfaces, often necessitating redecoration. O. Lodge (78) and J. W. Clark (78) have shown that dust remains suspended in direct-radiation heated rooms, e.g. open-fire heated, as walls and furniture are warmer than the air.

Large numbers of interior wear and tear particles are formed from culinary utensils, floor coverings, seating covers, clothing and footwear. Such wear is probably the source of large sunbeam motes. Knives constantly used for thirty years, not worn in cleaning or sharpening unduly, will lose an inch in length and considerably in breadth, whilst forks and spoons are similarly worn. Much of this may be swallowed. The insidious manner in which dust migrates into interiors is shown by its steady accumulation in closed houses.

Of the 11,000,000 tons of refuse per annum in Great Britain, interior and exterior fractions are complementary owing to constant exterior-interior communication. All individuals are dust-runners! Sprays and dust-laying compounds are now marketed, finding particular application in places like schoolrooms, and are often germicides for particular direction against bacterial dust. University laboratory and commercial-room tests with an electric floor-waxing device, without simultaneous dust suction, have increased the air dust-content 7 to 8 × normal, affecting health, labour, and possibly quality of finished goods (538). Microscopic examination of floor wood often reveals many impregnated dust particles, and with new wood particles are embedded in the swollen cells. An important museum finds dust impregnation greater and more permanent, and cleaning more necessary, owing to the relative jazz-walking—rather than straightforward stepping—of modern visitors, according to the Curator. Thus the "jazz age" supplements the industrial dust era. Non draught-creating fresh air streams, due to ventilation research, can now fill interiors. Meaning a more frequent air change, without filtering precautions more dust per unit time may be introduced. Except for this, better ventilation will introduce "purer," less microbic dusts, even with increased total amount. Since thermal precipitation will be lessened so will selective contamination, but exposed ledges, etc., may collect more dust in all probability.

Industrial interior dusts will be much more harmful than domestic ones, tending to produce a whole range of serious diseases. Headaches, bad appetites, etc., due to "crowd-poisoning" coincide with dense factory and large-building dust atmospheres. Cool air introduction is the best corrective giving freshness—whose lack is wrongly attributed to human emanations—removing dust and exhaled microbes which spread infection and may affect the respiratory membrane—L. Hill (226).

Dust accumulating at the Holy Sepulchre is competed for by the various communities always represented there.

SECTION TWO

DUST CONSIDERED SPECIFICALLY

CHAPTER VI

DUST IN EXPERIMENTAL SCIENCES

THE SCIENTIFIC RECOGNITION OF DUST.

THE place of dust in scientific recognition has been allotted only comparatively recently, for in this—in common with the empirical outlook, dusts (outside everyday life) are of but relatively modern significance.

Dusts belong scientifically to the colloid state, widespread attention to which was first drawn by Thomas Graham (353), who initiated the "colloidal condition of matter" and distinguished some of its underlying characteristics. Although dusts, as a class of materials were recognized before then on account of their function in other notable scientific phenomena, e.g. physiology, it would seem that their niche in the scientific mosaic awaited the scientific recognition of the colloid state. They find a place then—amongst other aspirants to the title—with what some regard as the fourth state of matter, the others, of course being solids, liquids and gases.

Colloids whose dispersion medium is air being termed aerosols, the majority of dispersed dusts will be aerosols. And this will particularly apply to natural dust dispersions, and in particular the staubosphere though, in particular cases the staubosphere will not be purely an aerosol, e.g. over active volcanoes of the peléean type at once emitting finely-divided dust, sulphurous and other gases, and water vapour. But when not aerosolic it will be difficult—particularly in case of mixed gases—to state the particular dispersion medium of the sol which they form. And, to be strictly accurate, aerosols themselves are a mixture of oxysols, nitrosols, argosols, etc.

According to the classification of aerosols due to W. E. Gibbs (354), all those formed by disintegration with particle units greater than 10^{-5} cm. diameter—this figure being that below which brownian movement is observable as exceeding gravitational movement—are dusts. Whilst this limit may be

adequate for all cases of artificial or mechanically-disintegrated dusts, it seems to be an unnecessary and undesirable restriction in the consideration of all kinds of natural dust aerosols—an object of this monograph. It is proposed, therefore, to widen the scope of the definition of dusts to include all possible cases in nature as well as artificial cases. This can best be done by decreasing the logical denotation. The notion of a lower limit of 10^{-5} cm., will therefore be omitted from the present definition of dusts.

Dusts will consist of all systems, sol or gel (whether aero-hydro-, oxy-, or otherwise) whose constituent solid particles have a decreasing life tendency of particle size by formation or existence, and are of such dimensions that in gel form they are susceptible of being reversed into sol form by more or less normal natural processes. This definition lays greatest stress on the decreasing life tendency of particle size—Blacktin (355)—which, whilst covering all cases of artificial disintegrated aerosols greater than 10^{-5} cm. diameter, also includes all possible cases of natural aerosols of no-matter-what particle size. In nature this range must be exceedingly wide when it is considered that the largest proportion of natural dusts are formed by continuous particle-size reduction, starting with large solid objects such as rocks, and reaching unknown lower limits which may, possibly, be sub-ultramicroscopic.

There can be little doubt of the reality of this decreasing life tendency of particle size throughout natural dust systems, i.e. the staubosphere (*cf.* Dust in Geology) whilst, in artificial systems, the decreasing tendency is recognized by the classification of dust aerosols, as aerosols formed by disintegration.

Close Relationship of Smokes and Dusts.

In all previous pages smokes have been referred to and more or less indiscriminately discussed as dusts, forming part of the staubosphere, and little distinction has been made between them.

In the study of aerosols, however, a scientific distinction has been made between smokes and dusts, but the previous jointure has been justified because, in the scientific distinction, smokes as such must eventually become dusts as such. And this is what actually happens in practice. For consider the production of smokes in the atmosphere. The particles at first are probably in the size neighbourhood of large molecules,

say 5 millimicron (*uu*) and well below the lower limit of microscopic visibility, viz. 200 millimicron. But they rapidly increase in size and agglomerate until, ceasing to do so, disintegration commences and they have become dusts. The transition from smokes to dusts is, therefore, continuous and since dust particles (which have not previously been smokes) may exist of the dimensions at which smoke particles originate, smokes have been included in dusts as species are included in genera. In the classification due to Gibbs (354) whilst solid particles are continuing to grow up to 100 millimicron they are smokes, and whilst still continuing to grow from 100 millimicron upwards they are clouds. But immediately they cease growing and commence to disintegrate they are dusts until attaining the lower limit of 100 millimicron.

The staubosphere is one vast aerosol of indeterminable varying component aerosols of given particle dispersion. It has been pointed out in an earlier section how the solid phase —the disperse phase—of this aerosol is being constantly transformed from the terranean limb and the stratospheric limb. How it consists of particles of all dimensions, histories and ages. Throughout this vast aerosol two kinds of systems, viz. those of increasing particle size (smokes) and those of decreasing particle size (dusts) will be constantly superimposed—the former always tending to pass into the latter, but not the latter into the former. Thus, over a city before the daily smoke aerosol commences to be formed, there will be a continuous dust aerosol, and this will continue when the smoke aerosol is in full existence. The latter will, gradually, merge actually and by classification into the former. The smoke aerosol of one period, therefore, becomes the dust aerosol of another, but there is always the residual dust aerosol, whether smokes are being formed or not, e.g. in the alps.

Modes in which Dust is of Scientific Importance.

There are three ways in which dusts will be concerned in the pursuits of pure science. These spheres of contact vary (*a*) as regards extent of application, and (*b*) as regards degree of recognized functioning in scientific experimenting. In general (*a*) and (*b*) will vary inversely. Thus in the first way the staubosphere permeating atmospheric space will be present to some extent as a condition or incident in all experiments or scientific phenomena, except where very drastic steps are

taken to exclude it. In this way it will be least recognized or taken note of by experimenters.

In the second way dusts (as part of the visible or invisible staubosphere) will consist of one of the essential conditions of certain experiments, and in such cases its presence will necessarily be recognized to a greater extent by the experimenters, since its state and amount will enter into their experimental calculations.

In the third way, dusts will be designedly studied on their own account. Its presence will, consequently, be a planned essential, and it will necessarily enter fundamentally into scientific calculations.

Dust in Relation to Units of Matter.

Perhaps the most crucial and apposite test which nowadays may be invoked of the importance of a subject is whether it has significance in the realm of pure science. And in applying such test to the present subject some speculation might be ventured as to whether Newton had a parallel in mind when he enunciated the corpuscular theory. Whether, in fact, the conception of corpuscular bodies was born in the notion of exceedingly small dust particles. It may be that Newton was aware of the exceedingly important fact that the reality of daylight is owed to light scattering by dust—an association which might readily project dust, in a fertile mind, into a generalized theory of light. If for no other reason than its association with daylight, dust deserves to be classed amongst mankind's most important studies. But before the vogue of the electron, a corpuscle could not have been a very different theoretical body from a dust particle of very small dimensions. The gradation from dust particle to molecule may be continuous—qualitatively and quantitatively. For in the gaseous and particulate phases of matter, the molecule being the largest independent theoretical unit, there is necessarily no "efficiency bar" to prevent molecules aggregating until a very minute dust particle is produced, or dust particles becoming so minute as to be almost of molecular dimensions. If, therefore, corpuscles were not regarded as essentially electronic, but rather as essentially material particles emitted from bodies, and atoms could not exist alone, corpuscles must have been in the region of molecular dimension, where also dust particle dimension was not far afield. Were this reasoning sound,

corpuscles and dust particles of small dimension must have seemed very much akin in conception. Both would be invisible to the naked eye; one—the corpuscle—was the unit of light; the other—the dust particle—was necessary to the existence of light. Certainly a very close, pertinent relationship.

But whatever the pre-electronic relationship between corpuscles and dust particles was conceived to have been, the Huyghenian wave motion theory and the converging post-electronic explanation of the nature of corpuscles put the latter in a quite different category from the material particle, no matter how close in dimension this latter may approach to the molecule.

The barrier—which perhaps after all may be no such great barrier—between force and matter, now separates the corpuscle and the particle, and the Quantum theory—by exerting a revivifying force on Newton's emission theory (356)—bends towards showing that the barrier is probably insubstantial. This serves to bring out in great significance the importance of the dust particle. For, shorn of its erstwhile possible fundamental relationship to the suggested unit of light, it retains its importance and significance, nevertheless, in the study of light—whether in laboratory or atmosphere; whether in delimiting the boundaries of the light pencil in the laboratory, or in producing particularly beautiful sunsets.

Light and the dust particle are still very closely akin by profession and practice—if no longer by birth. And as is so often necessarily the case, a relationship established in the physical sphere produces a less-fundamental echo in the chemical sphere. How different would the study of solutions become were it possible to exclude all dust particles—even of ultramicroscopic dimension? Every crystalloid solution is, at once, a colloid sol (ignored as such) by virtue of this impracticability. To what extremes might not supersaturation be carried?

The importance of the dust particle in the pursuit of pure science, may therefore be regarded as the criterion of its importance—ever-growing—in all spheres of human interest and endeavour.

The given spheres of contact which dust has with pure scientific pursuit will now be considered in greater detail. Such consideration will be subdivided into:

(*a*) Contact of an incidental nature.
(*b*) Contact of a fundamental nature, and
(*c*) The scientific study of dusts.

(*a*) WHERE DUST IS OF IMPORTANCE TO SCIENCE INCIDENTALLY.

In this sub-section the most widespread importance of the staubosphere is that of its extraordinary significance as the stepping-stones which visibly mark the passage of light.

This immense function known to exist as a result of experiments by Tyndall (370), and the resulting knowledge that light is itself invisible, even alone, ranks the staubosphere of the order of importance of the atmosphere. Moreover, without light scattering by the uncountable particles of the staubosphere, the sun's heat would be unbearable—despite that absorbed by water vapour. And more so, because without dust intervening rainclouds could only form with difficulty, and each night would be intensely cold and every day intensely hot.

The ethical effect of colour in nature could not, of course, be existent without dust, for although light may be scattered both by dust-free air and air molecules, according to Cabannes (83) and Rayleigh (23), blue only would be visible. And again, if all particles of the staubosphere were of identical size, all light would be of one colour dependent on that particle size. The blue colour of the sky has been known to be due to sunlight scattering since about 1500.

Particles are capable of reflecting or refracting light of all the solar spectrum colours whose wave length is less than their particular diameter. Other light is scattered, each particle it meets forming a fresh wave-front, and all scattered light being plane-polarized—Rayleigh (108). Thus a particle of, say, 0·45 micron diameter would not reflect red light of wavelength, say, 5,600 angstrom units, i.e. 0·56 micron, but indigo or violet light of, say, 0·40 micron and all up to 0·45 micron. The beautiful colour effects in nature, therefore, as well as the peculiarly brilliant ones after volcanic eruptions are due to the very varied particle sizes of the staubospheric units. And since these sizes will be continuous between the largest and smallest dimensions, the colour variations due to the blending of the spectrum colours in different degrees will be innumerable.

Of course, this fundamental characteristic of the staubo-

sphere is no more effective to-day than it has ever been (except as regards any unassessable variations in the dust population) but with the modern vogue for sunshine and the ultra-violet, its emphasis is becoming continually more important.

Daylight is, therefore, sun energy (partial) dispersed by the staubosphere.

The staubosphere, more sensitive to thermal radiation than pure gas (84) also absorbs the infra-red sun radiation, i.e. heat waves, warming the surrounding air by convection and decreasing the diurnal temperature range. The staubosphere, consequently, makes life possible on the earth.

The staubosphere particle dimension probably continues without break down towards molecular dimension, i.e. far below the least wave length of visible light, and has a similar amelioration effect in that size range with regard to solar radiation of ultra-violet wavelength of from 400 to 150 millimicron, that it has in the infra-red region. The very powerful cosmic rays also, which penetrate to the sea-depths, may possibly be modified in effect by the staubosphere.

A point well worthy of note—since it has a close bearing on the vexed question of the arrest of solar radiation by city smokes and dusts—is that unless the staubosphere contains particles of diameter less than the wavelength of ultra-violet light it will have no effect in stopping the beneficial ultra-violet light, but only in stopping the visible solar radiation. But numerous experiments have shown that rickets and other rachitic diseases in children due to lack of ultra-violet-formed vitamin B, invariably ensue when the staubosphere over-absorbs solar ultra-violet radiation, i.e. of wavelength, say, 100 millimicron in the region where brownian movement commences. This is an important conclusion as indicating the reach of particle size towards molecular dimensions which however at, say, 1 millimicron is still some way off.

THE INDETERMINATE PENETRATION OF THE STAUBOSPHERE.

The staubosphere being continuous throughout the region of the earth's atmosphere, as may be concluded from world-wide particle counts by different observers, all scientific experiments in no matter what branch of knowledge will have a basis of mostly invisible coincident dust particles—whether recognized or unrecognized by the investigators in particular cases. Where the material studied is gaseous or

liquid, dust particles will be dispersed throughout it in lower or higher concentration. Where it is solid they will be attached to its surface and fill the intervening space between the material and the eye of the observer. Small dust colonies will arise at pore entrances, increasing in frequency and size with increasing porosity. This is inevitable as a result of natural process, and whilst precautions are often taken to reduce this dust population as much as possible by, say, pre-filtering air or gases which are to be used for given experiments, it is almost impossible to totally exclude dust and in the majority of cases its presence is ignored.

It will thus be realized that, represented by dust, the colloid state is a continuous one throughout nature, coextensive with atmosphere. And this can be extended (not aerosolically of necessity) to the soil, and to minerals (by virtue of gases enclosed in their pores) and alloys of metals and eutectics by formation. The "purest" solution and the "purest" gas are likewise also colloid systems, no matter how rare the dispersion or how few the minute particles which must, almost necessarily, be gathered from walls of containing vessels if not already suspended in the liquids or gases themselves. How is it possible to prevent the settling of some dust on a crystal of "pure" solute whilst it is being transferred to the balance, or from thence to the solvent, in normal operations? How possible to form, say, an organosol in a liquid dispersion medium by chemical action, which is not already—to some extent—a sol, with some portion of the staubosphere as the disperse phase? The general tacit conspiracy to ignore these realities does not destroy their presence. Their existence is confirmed by the necessity to plug the mouth of a vessel in which a supersaturated solution is being prepared, floating laboratory dust containing many foreign salt particles. This universality of the staubosphere has very important functions which are recognized, and probably many which as yet are not seriously considered though they must produce effects.

Dust, Rainfall and Light Dispersion.

Whilst the fundamental importance of dust particles for rainfall has been referred to previously several times in a general sense, the growth of meteorology as a science calls for further mention here of this other widespread function—as extensive as the staubosphere itself—of rainfall production,

ranking with dust as daylight producer in establishing it as as great a prime necessity as the atmosphere. Coulier (480), E. Mascart (357) and J. Aitken (29) have shown that cloudy condensation in the atmosphere is always caused by condensation on some dust particle—which may here include droplets—except with very high supersaturation, say 8 × normal, when molecular aggregates or molecules may be the nuclei. Fogs, clouds, mists and probably rain—other than the finest—would not therefore be formed without dust. Whilst this view is now somewhat modified by that which accepts ions as nuclei of condensation above a high supersaturation in addition to solid nuclei—C. T. R. Wilson (1), Lenard (2)—it would be interesting to know what part dust particles themselves play in the production of ionization, and also whether in their complete absence precipitation at all could occur, although cloudy condensation may be produced by supersaturation in the presence of mineral acid vapour. There is some difference of opinion as to whether the blue of the sky is due to dust particles fine enough to reflect the blue of the spectrum, as maintained by Newton, Stokes and Rayleigh (23) or to the oxygen content of the air. Dewar took the latter view since liquified oxygen is blue, and Nichols (24) by spectrophotometric measurements, suggested turbidity of dispersed light might be due to ozone or fluorescence, and appreciably affected by light reflected from cloud masses, earth, mists, etc.

The gorgeous colours due to supplementary volcanic dusts are described by E. Whymper (358), explorer and mountaineer, as produced by Cotopaxi. "We saw a green sun and smears of colour something like verdigris-green high up in the sky, which changed to equally extreme blood-reds, or to coarse brick-reds, and then passed in an instant to the colour of tarnished copper or shining brass. No words can convey the faintest idea of the impressive appearance of these strange colours in the sky—seen one moment and gone the next—resembling nothing to which they can properly be compared and surpassing in vivid intensity the wildest effects of the most gorgeous sunsets."

Essential as is the staubosphere to diffuse sunlight, produce daylight and thus prevent sun and stars being seen in the day against a black background from a glowing earth, it has an optimum value which is not determined, but beyond which (as above explained) valuable sunshine and ultra-violet rays

are extracted. Seen from the earth through the staubosphere the sun is white and bright, but were it observable from beyond the stratospheric limit of the atmosphere it would appear bluish-green, like the mercury-vapour flame. Both the Belgian (A. Piccard) and Russian investigators who recently ascended into the stratosphere, agree as to the deep purple colour of the sky from that vantage " ground "—which must always be seen through glasses. These differences in colour are due to the abstraction by the staubosphere of violet and ultra-violet complements, and the change from blue to deep purple in the sky colour at above, say, 10 miles height, indicates the absence of dust at that height of diameter greater than the wavelength of violet light, i.e. 3,000 angstrom unit, or 3×10^{-5} cm. This is a very important conclusion of the observation.

Other Examples of Incidence of Dust.

In determining the value of the electronic charge *e* by studying gold, silver and mercury droplet movements under electric field influence as Millikan (98) previously did with oil droplets, Ehrenhaft and others (100) obtained a much smaller value, which Millikan suggested as possibly due to dust particles attached to the metallic drops. Regener (101) considered that adsorbed gas was also operative.

In all processes—natural or scientifically controlled, where they occur—dust particles are the enemy of supersaturation and, by consequence, the promoter of crystallization, condensation or precipitation. Though in supersaturated solutions a small crystal of the solute will best promote precipitation, dust particles of other materials will also produce a similar effect. This is an exceedingly important function of particles and leads to the recognition of an important general coincidence due to dusts. This is that whilst dust particles are chiefly responsible for precipitation of liquid (e.g. rain) from supersaturated gases, they are likewise responsible for the precipitation of solids from supersaturated liquids. This is a striking and important parallel and suggests the further one that since ions can promote precipitation in air, they may possibly, likewise, promote precipitation in liquids (i.e. in a physical sense, and not primarily by chemical union). In any case this parallel indicates that the processes of precipitation throughout all gaseous and liquid systems are ultimately dependent for pro-

motion on the underlying colloid system of the staubosphere, so often disregarded as an important factor. In this connection it may be mentioned that A. Findlay and colleagues have concluded the "head" of beer to depend somewhat on "nuclei" on the walls of the containing vessel.

Throughout space where it exists, the staubosphere has a no less important effect on the propagation of sound than on that of light. In the case of sound waves, the greater the dust particle content of the air the easier are they propagated owing to the increasing density of the medium. In the case of light waves a certain dust population is essential—as already shown—for the production of their essential effects. Beyond this concentration, however, whilst the propagation of sound is still augmented, that of light is hindered and diminished. This distinction is doubtless due to the difference of wave-length order and direction. The important practical effect, so well known, arises that a heavy air dust-content or its consequent mist or fog will arrest the passage of light and facilitate that of sound.

Another wide, incidental function of dust (i.e. incidental as regards recognition) is its office in the providing of thin films on the surfaces of solids which are operative—partially, if not wholly—in producing electrification on the rubbing of such solids by another body. Thus it is a practice of long-standing, of course, to demonstrate the production of either positive or negative static electricity, as the case may be, dependent on the respective choice of rubbed and rubbing materials. Only very recently has it been shown by Shaw and Jex (320) that variation of electrical charge does not, as was previously thought, depend essentially on the visible materials brought into apparent contact, but rather on the nature and amount of the invisible film of contamination (on the visible objects) which really embrace the region of contact. These films are sure to contain a proportion of fine dust particles which have thus, incidentally been playing a part in producing a phenomenon for long unexplained. Rayleigh (102) has also shown that dust or grease on their surfaces promotes the coalescence of droplets.

The existence of dusts has been of importance in providing a basis for the considerable work which has been done on the "heat of wetting" and adsorption determinations, leading to such scientific contributions as those of F. G. Tryhorn and W.

Wyatt (365), H. Gaudechon (360), W. Patrick and F. V. Grimm (361), L. G. Gourvic (362), Schwalbe (363), Jungk (364) and A. B. Lamb and A. S. Coolidge (366). Haze, due solely to dust—Aitken (28)—has provoked the important recent invention of infra-red photography.

To the alchemists—and the kings, emperors and others hoping to gain from their labours—dust seems to have been the world's outstandingly important form of matter, for they all sought the *powder* of projection (" which the vulgar called the philosophers' stone ") to work the longed-for miracles of perpetual youth and metallic transmutation—R. B. Pilcher (525).

Tyndall (359), under the title " The Floating Matter of the Air," refers to the extreme difficulty of extruding dust particles from his experimental tubes, and obtaining them " optically empty." No matter how well-cleaned were his tubes, air was always present and sure to deposit some impurity. He states: " I did not imagine the dust of this external air could find such free passage through the caustic potash and sulphuric tubes. They also passed with freedom through a variety of ethers and alcohols. In fact it requires long-continued action on the part of an acid, first to wet the motes and afterwards to destroy them." The dust particles gave much trouble, " and only with a great deal of searching out of disturbances " could his tube be made to contain nothing competent to scatter light, i.e. optically empty. He concludes: " It is needless to dwell upon the possible influence of the floating organic matter of the air upon health. Its quantity, when illuminated by a powerful and strongly concentrated beam, sometimes appears enormous. One recoils from the idea of placing the mouth at the intensely illuminated focus and inhaling the swimming dust revealed there. Nor is the disgust removed by the reflection that at a distance from the focus, though we do not see the dust, we are breathing precisely the same air. The difficulty of wetting it before referred to, may render this suspended matter comparatively harmless to the lungs, but when these are sensitive, its mere mechanical irritation must go for something. Perhaps a respirator of cotton wool might in some cases be found useful." It has since been shown by Rayleigh (107) that the production of a Tyndall beam does not necessarily imply dust, since both dust-free gases and true solutions will also exhibit such beams.

The ultramicroscope was, of course, not discovered by Zsigmondy and Siedentopf (367) when Tyndall (359) believed, after such great pains, that the air in his tube was at last optically empty, nor, therefore, could the finest members of the staubosphere be known of, which would have still more intensified his disgust of the "floating organic matter" breathed. Moreover, his experiments carried out at the Royal Institution, at a period remote from modern dust incidence, could not, in that locality, be immersed in anything like so dense a staubosphere as obtains in our industrial cities. Further work of Tyndall (368) refers to the amount of radiant heat absorbed by the water vapour of the atmosphere. He showed that over 70% of heat absorbed by its passage through air was absorbed not by the gaseous content of the air, but by other substances, and although he was chiefly thinking of water vapour, there can be little doubt that dust content plays an important part in this sense.

In the experiments of S. Leduc to simulate plant growth (intussusception) with chemicals, he used small grains of sugar and copper sulphate, in proportion 2 to 1.

Distinct from these various important ways in which all the experiments of pure experimental science are shown to be performed in complete immersion in the staubosphere are the world-wide effects of the latter in the social sciences. All history has been fashioned within the staubosphere, and since it still is, and always has been, an immense physiological and everyday factor, sociology, political and economic science and all the humanitarian sciences are, indirectly, different from what they would have been, divorced from the incidental operation of dust. The evidence for this, perhaps, apparently strained statement is that the operations of the human mind vary with the physical condition, and the physical condition varies with the condition of the air breathed. The human exodus into relatively dust-free air at all suitable opportunities points the truth of the latter conclusion. The difficulty of realizing this is measured by the lack of any occasion when dust has not, to some extent, been present. But those whose experience allows them to compute the bracing mental effect of mountain air in lungs and blood will be best able to realize what the cumulative effect of a continuous state of such well-being would be likely to be, and have been.

This sub-section cannot be better concluded, in the extenua-

tion of the increasing incidental importance of dust in scientific work, than by quoting A. W. C. Menzies (369) on intensive dessication, to demonstrate the insidious importance of dust. He states: ". . . Recent work in this laboratory (Princeton University, U.S.A.) has again brought to our attention the importance of atmospheric dust. . . . The presence of the higher hydrate, the function of which may possibly be filled by other solids, isomorphous or otherwise, furnished by dust, promotes the reaction. Dust may even furnish particles of salt that are deliquescent under the conditions of the experiment, thus making possible hydration of the salt studied by water in the liquid phase. One could not, therefore, hope to observe, nor does one observe, the behaviour mentioned above, if starting nuclei, furnished by dust, were thickly spread over the surfaces of the crystals of the lower hydrate. In such a case the induction period would be lacking, and the rate of reaction a steadily diminishing one as the zone of reaction progressed, with diminishing area, towards the centres of the crystals, and this has been the common observation in the past. . . . With reference to the effect of intensive dessication on the boiling point of liquids, F. O. Rice has very properly considered the presence of dust as affecting superheating, although without illuminative result, and he pointed out, further, that dust particles present, if they also must be dried, will delay the drying of a system containing a liquid. It may be added that certain substances contributed by dust particles may promote the changes under observation just as effectively as does water itself. One should recall, also, the independent and concordant findings of Wolski and of Kenrick that ordinary distilled water contains about 20,000 motes per c.c. Other distilled liquids may be in like case. Moteless water shaken in ordinary 'clean' glass apparatus rapidly acquires many motes. Even dismissing from consideration the motes suspended in the liquid, one is able to bring forward additional reasons, beyond the mere sealing of capillaries, for timeously heating to the fusion point all glass apparatus designed for work on the effects of intensive dessication. For example, this fusion of the glass may flux and fix the loose scale that yields the motes, and will certainly enormously diminish the area of the quasi-porous internal surface of glass that has been cleaned and roughened by cleaning solution. Again, the fusion process may engulf and incorporate beneath a relatively plain glass

surface, dust particles of such ubiquitous salts as sodium chloride, as well as the ash of those organic particles which, in using Baker's air current technique rather than the vacuum technique, for drying apparatus, have been burned to ash. . . ." Portions not indicating the significance of dust have been omitted, so that the full meaning of the original is not presented above.

The fact that incidentally-occurring dust of unknown composition can act catalytically must be noted. It is almost suggested by the tenor of the above quotation. Thus dust particle surfaces may act catalytically in the decomposition of hydrogen peroxide, or the oxidation of benzaldehyde—E. K. Rideal (437). Whilst inhibitors act oppositely to catalysts, retarding reactions, they are often thought to operate by being adsorbed on to the surfaces of dust particles on vessel walls which particles were operating as catalysts before being " poisoned " by absorption of the inhibitor. But if the theory of the origin of life on earth from the primordial jelly, be the correct one, then dust is at the basis of life itself, for the promotion of life from such a basis is held to be dependent on the catalytic action of fine particles by its provision of indefinite chemical increase.

Contact of a Fundamental Nature.

But for the existence of dusts some of the most fundamental conceptions of modern science might probably be yet unformulated. Thus, for instance, the invisibility of light, the brownian movement, the measurement of sound waves, and the ultra-microscope might still remain to be discovered. It is not too much to state that these are fundamentals without the knowledge of which made possible by the existence of dusts, scientific knowledge would be much less advanced in very important directions than it now is.

In brownian movement the nearest approach known to the actual observed existence of molecules is embodied. In this closest link to the practical confirmation of the existence of molecules proved by theory, the observation of brownian movement itself was only made possible by particulate matter. And this is the way in which it is still best displayed ultramicroscopically. The continuous movement of microscopic animalculae suspended in water was noted by Leeuwenhoek in the 17th century, and of water-suspended pollen grains

(clarkia pulchella) by Robert Brown (460), the botanist, in 1827, but the investigations of the latter supplied the first visual evidence of the actual participation of molecules in the scheme of things, and by studying the vivified dust particles Wiener (461), Exner (462), Dancer (463), Jevons (464) and Cantori (465) led up to the demonstration by Gouy (466), Ramsay (467) and Carbonelle and Deslaux (468) that the bombarding effects of molecules were the cause of the vivification. For present purposes, the upper limit of brownian movement may be regarded as applying to particles of 10^{-5} cm. diameter, for above this diameter particle velocity due to gravitation is greater than that due to brownian movement.

A no less delicate distinction than that between the knowledge of the existence of molecules and the observation of their effects, obtains between the existence of light for making objects visible and the question of the visibility of light itself. Again, the dust particle in the hands of Tyndall was to be the important instrument of solving this latter problem.

Dust Proves the Invisibility of Light.

Whilst the experiments of Tyndall on the subject are classical, it will be of interest to describe how he used dust particles to prove the invisibility of light itself. Tyndall (370) describes the apparatus he used and the results obtained as follows: " A number of chambers or cases were constructed, each with a glass front, its top bottom back and sides being of wood. At the back is a little door which opens and closes on hinges, while into the sides are inserted two panes of glass facing each other. The top is perforated in the middle by a hole 2 ins. in diameter, closed airtight by a sheet of indiarubber. This sheet is pierced in the middle by a pin, and through the pinhole is passed the shank of a long pipette ending above in a small funnel. A circular tin collar 2 ins. in diameter and 1½ ins. deep surrounds the pipette, the space between both being packed with cotton wool moistened with glycerin. Thus the pipette in moving up and down is not only firmly clasped by the indiarubber, but it also passes through a stuffing-box of sticky cotton wool. The width of the aperture closed by the indiarubber secures the free lateral play of the lower end of the pipette. Into two other small apertures in the top of the chamber are inserted, air-tight, the open ends of two narrow tubes intended to connect the interior space with the at-

mosphere. The tubes are bent several times up and down so as to intercept and retain the particles carried by such feeble currents as changes of temperature might cause to set in between the outer and the inner air. The bottom of the box is pierced sometimes with two rows, sometimes with a single row of apertures in which are fixed air-tight, large test tubes intended to contain the liquid to be exposed to the action of the moteless air. The cases have varied in capacity from 1,666 to 451 cu. ins. On September 10 the first case of this kind was closed. The passage of a concentrated beam across it through its two side windows then showed the air within it to be laden with floating matter. On the 13th it was again examined. Before the beam entered and after it quitted the case its track was vivid in the air, but within the case it vanished. . . . In no single instance, on the other hand, did the air which had been proved moteless by the searching beam, even when raised to over 90 degrees, manifest the least power of producing bacterial life, or the associated phenomena of putrefaction. The power of developing such life in atmospheric air, and the power of scattering light, are thus proved to be indissolubly united. The sole condition to cause these long-dormant infusions to swarm with active life is the access of the floating matter of the air. After having remained for four months as pellucid as distilled water, the opening of the back door of the protecting case and the consequent admission of the mote-laden air, sufficed in three days to render the infusions putrid and full of life. That such life arises from mechanically suspended particles is thus reduced to ocular demonstration. Let us inquire a little more closely into the character of the particles which produce the life. Pour eau de cologne into water, a white precipitate renders the liquid milky. Or, imitating Brucke, dissolve a clean gum mastic in alcohol and drop it into water. The mastic is precipitated and milkiness produced. If the solution be very strong the mastic separates in curds; but by gradually diluting the alcoholic solution we finally reach a point where the milkiness disappears, the liquid assuming by reflected light a bright cerulean hue. It is, in point of fact, the colour of the sky, and is due to a similar cause, namely, the scattering of light by particles small in comparison to the size of the waves of light. When this liquid is examined by the highest microscopic power it seems as uniform as distilled water. The mastic

particles, though innumerable, entirely elude the microscope. At right angles to a luminous beam passing among the particles they discharge perfectly polarized light. The optical deportment of the floating matter of the air proves it to be composed in part of particles of this excessively minute character. When the track of a parallel beam in dusty air is looked at horizontally through a Nicol's prism, in a direction perpendicular to the beam, the longer diameter of the prism being vertical, a considerable portion of the light from the finer matter is extinguished. The coarser motes, on the other hand, flash out with greater force because of the increased darkness of the space around them. It is, I hold, among the finest ultra-microscopic particles that the matter potential as regards bacterial life is to be sought. Now the existence of these particles foreign to the atmosphere, but floating in it is as certain as if they could be felt between the fingers or seen by the naked eyes."

The above quotation from Tyndall's work has been given at length so as to include reference to bacterial life and its coincident existence with atmospheric dust, because it is of importance for a later section. It is shown how extremely near Tyndall was to the discovery of the ultra-microscope, and indicates how great advances might thus have come very much sooner, had he but thought of using a microscope as well as a nicol prism.

Dust Fundamental in Other Spheres.

All students of physics are familiar with the classical experiment of Kundt's tube which is used for demonstrating the visible impression of passing sound waves. The impression is, of course, produced in dust—generally lycopodium powder, being of similar-sized, almost spherical units, which readily flow almost like a liquid—and just as in the case of brownian movement, when dust is the agent by which visibility is brought as near as possible to molecular existence, so dust is the important means of first making visible the path of advancing sound waves. The manner in which the scientific uses of dust increase, even fundamentally, is shown by the recent discovery of Andrade that cigarette smoke—a potential fine dust—is an ideal indicator for sound-wave measurement.

Whilst the discovery of the brownian movement through the prime agency of dust made visible an immediate effect of

molecular action, and thus provided the next best thing to the actual visibility of molecules as a proof of their existence, there was a wide range of dimensions from 0·2 micron diameter (the lower limit of microscopic visibility) to 0·001 micron (the order of molecular diameter) which remained quite dark to the inquiring vision of man, there being no means of rendering visible particles of diameters between these limits. Had it been necessary to fabricate particles between these dimensions before a means of seeing and studying them could be found, the task might have been well-nigh impossible owing to the tendency of mechanically-disintegrated particles to immediately reunite under the action of brownian movement when of lesser diameter than 0·1 micron—though precipitation from solution might have helped. And had there not been in nature an immense particle population between the above size limits, the *fundamentum relationis* for the discovery of principles, or the invention of an instrument to render visible for study such a particle population, would have been non-existent. Had this absence of objects which could have shown the powers of the ultra-microscopic principle obtained, the principle could probably not have been discovered, nor, consequently, the ultra-microscope itself. Invented in 1903 by Zsigmondy and Siedentopf (367), the ultra-microscope is directly due to the existence of such particles as may constitute the finer fraction of the staubosphere of diameter less than 0·2 micron—though embodied as the disperse phase in colloidal gold ruby solutions which Zsigmondy first used it to study. The use of the ultra-microscope in the study of the field to which it is applicable may be truthfully said to have opened up new fields of scientific knowledge and endeavour. The possibility of this great advance was only provided by the existence of particles between the size limits indicated, and the very stuff of the existence and continuance of the advance, whose far-reaching importance cannot yet be fully comprehended, is that particle realm which made its initiation possible. Additionally, of course, all other kinds of colloidal dispersions have been studied thereby, as by de Broglie (20), who first quantitatively studied tobacco smoke in 1909, though gaseous systems were first studied by Bodaszewski (19) in 1881, before the ultra-microscope was available, observing particle movements analogous to what the kinetic theory might predict for gases. It is readily seen, therefore, that by making possible the ultra-microscope,

particles have carried the practicability of the visual study of the fine states of matter markedly towards those molecular dimensions where, by providing the essential for the discovery of the brownian movement, they had already produced intimate visual evidence of the existence of molecules. All strictly true colloidal systems are regarded as having the units of their disperse phases between the size limits of 0·1 micron and 0·001 micron diameter. The limit of microscopic visibility being 0·2 micron, it is at once obvious that all information derived from actual visual observation of the disperse phase of colloid systems must be gained through the ultra-microscope. The possibility of the latter's existence—be it again stated—is fundamentally based in the existence of the staubosphere. And the importance of colloid systems is immense and growing, and alike important in pure and applied science, industry and medicine, and the fundamental processes of all life. The lower limit of ultra-microscopic visibility being 0·005 micron, below which is the region of molecular dimension, dust, then, if indirectly, has made possible the knowledge of all the important ramifications of the colloid state, stretching to such molecular dimension. This is a further conclusion of the importance of fine matter, ranking in calibre with those indicating its equal essentiality with air and water in the maintenance of life.

In all branches of science where applicable, dust is of exceeding importance, due to the manner in which a mathematical principle of its formation gives increasing scope to the manner in which it can physically and chemically react with other substances or particles. Thus considering that all dust particles may approximate to spherical shape, the successive halving of the diameter of spheres involves the successive doubling of the ratio of surface area of the sphere to its volume. So that the same weight of the same material divided into spherical particles of diameter, say, x, possessing particle surface area, say, y, will on further division into spherical particles of diameter $\frac{x}{2}$ possess total particle surface area $2y$. Or, total volume remaining constant, total surface area of particles varies inversely with spherical particle diameter. This fact is made great use of in all scientific reactions or conditions when maximum surface is an essential, or of outstanding importance. It largely accounts for the reduction into dust

form of all sorts of reagents and materials which would not otherwise be so reduced, and is a further cause of the great importance of dust. Since many scientific effects such as dissolution, adsorption, absorption, sorption, nascent action, and numerous others, constantly supplemented, are functions of surface exposed when they are operative, the number of materials artificially disintegrated into dusts is legion. And whilst, for instance, many chemical reagents may be supplied in finely-divided form as a matter of convenience in manufacture, many which are not are reduced to powdered form in the laboratory prior to use for this reason. This mathematical concomitant of dust is, therefore, properly used, a great time saver and promoter of actions which might otherwise be tedious. This constitutes a quite vast, though little-formulated manner, in which dusts enter into science, though Lang and Lloyd (34) have discussed increased inflammability owing to increased specific surface of a substance, and many other workers have discussed special aspects.

In 1809, E. F. F. Chladni the "father of acoustics" exhibited the now-famous Chladni's figures before the French Institute, creating such interest amongst the members—including Laplace—that Napoleon had Chladni repeat the demonstration in the Tuileries, and gave him 6,000 francs to translate his "Akustick" into French. To produce these classical figures over a hundred years ago, Chladni employed that widespread dust—sand. Quite recently, however, more refined methods have been used in the production of Chladni's figures (526).

It is permissible to inquire what part dust plays in such a modern branch of scientific study as the Liesegang phenomenon and periodic precipitation. A vast literature due to the findings of many workers has accumulated on this subject since its original observation by Liesegang. This has been excellently summarized and discussed by E. S. Hedges (371), but although dispersed dust particles must undoubtedly have an influence on the formation of periodic precipitates, this aspect does not seem to have received serious specific consideration by workers, though S. C. Blacktin (372) records the discovery of a further periodic structure—probably of a purely physical nature—built by the spreading of oil drops through carbon particle film.

The frequent use of all sorts of dusts for general purposes in scientific manipulation may, perhaps, be well-typified by

lycopodium spores. Lycopodium finds ever-increasing scientific uses because of its smallness of particle size, and its stability of shape and condition.' It would be difficult to state when it was first brought to the assistance of those sciences other than that which classifies it. But, even since its classical use in Kundt's tube, its services have tremendously increased. In developing his argument leading from the equi-partition of energy to his first method of determining N—the avogadro constant—Perrin (17) states : " Let us now consider a particle a little larger still, itself formed of several molecules, in a word a speck of dust."

Some of Sir W. Crookes' greatest discoveries, e.g. that of thallium, were born in his first using a spectroscope to analyse the constituents of flue dust.

Particulate matter, as dust, powder, or colloidally (heterogeneously) has immense importance in the promotion and rapid progression of chemical reactions, i.e. catalytically. In this connection it comprises the essential basis of huge chemical industries, e.g. sulphuric acid manufacture (contact process) and nitrogen fixation. To take full advantage of the great increase in specific surface presented by a dust, as contrasted with the surface presented by the same amount of the same material undisintegrated, supports such as asbestos or magnesium sulphate are employed, whilst other materials which act as promoters are added, so that promoted catalysts are now in general use. Thus, finely-divided platinum, platinum black, palladium, osmium, and other precious metals are employed, nickel-iron, ferric oxide and ruthenium. It is worthy of note that, in the contact process, the sulphur dioxide must be primarily completely free from incidental dust. B. Foresti (438) has studied the catalytic action of subdivided metals, and F. O. Rice (439) the catalytic activity of particles of dust, pointing out (*a*) that hydrogen peroxide may be heated for several days at 60 degrees C., without appreciable decomposition in complete absence of dust, (*b*) the thermal oxidation of dust-free sodium sulphite is immeasurably slow, and (*c*) the decomposition of hydrogen peroxide by ultraviolet light is roughly proportional to the dust content, the latter probably acting as photocatalyst, and in general Taylor's idea (440) of a catalytic surface is supported. S. Roginski and E. Schulz (441) have shown that when potassium chlorate is decomposed catalytically—Poliakov (442)—the decomposing

action of the generated gas is duc to very fine catalyst particles in the gas.

The great relative increase in specific surface which makes particulate matter valuable in catalysis, is instrumental in making dust the foundation of other important branches of industry, e.g. solvent recovery and scientific and technical operation, based upon the adsorptive process. Thus the properties and industrial application of carbon black, lamp black and bone black are dealt with by C. H. Butcher (456), and the production of activated carbon from various coals and other raw materials by A. C. Fieldner (457). Such dusts and others of similar properties have attained an international importance owing to their value in preventive warfare.

The geological volcanic dust, largely forming the ooze of the sea and ocean beds, has by its discovery on land in the western world, been of fundamental importance in deciding whether ocean beds have ever been uplifted to form dry land masses.

(*c*) THE SCIENTIFIC STUDY OF DUSTS.

As previously stated dusts belong scientifically to that sub-division of the colloid classification termed aerosols—a term due to Schmauss (69), H. Grimm (443) having later suggested an universal nomenclature for aerosols.

The colloid classification, strictly speaking, deals only with systems whose disperse phase consists of units—solid, liquid or gaseous—between the size limits of 1 uu and 100 uu. But whilst this upper limit of 100 uu particle diameter roughly represents that at which brownian movement ceases, and whilst it is convenient for differentiating between suspensoids and suspensions, or emulsoids and emulsions, in any wide survey of the classification involving naturally-grown as well as artificially-produced systems, the 100 uu limit must be transcended if the classification is to be retained to apply to such a wide sphere. Thus in the aerosol scheme due to W. E. Gibbs (354) previously set forth, 100 uu or 10^{-5} cm., regarded in the general colloid classification as the upper limit size for colloidal disperse units—J. N. Friend (188)—is but the transition point at which smokes cease to be regarded as such, and become clouds. Clouds in the particle-increasing direction, and dusts in the particle-decreasing direction may have units of any size greater than 100 uu. And it is obviously impractic-

able without either (*a*) the delimitation of a new scheme to cover natural aerosol dispersions of over 100 uu, or (*b*) more complete artificial control over natural forces to prevent the formation of disperse particles greater than 100 uu, to quite generally accept this upper limit of 100 uu for all colloid systems. In practically all those aerosols named smokes, after formation, the history of the system is one of continuous agglomeration of smaller particles to larger. This proceeds as a natural function without respect for the general colloid upper size limit of 100 uu, and the system, continuously changing within its own proper limits, must be considered colloidal throughout its life. Similarly with dust systems, colloidally classified as such. Whilst, eventually, their disperse units may all reach diameters of less than 100 uu, in nature this must occur as a gradual transition from particles of greater than 100 uu. This upper limit of 100 uu, whilst susceptible of application to suspensoids and emulsoids where, formation generally being artificial, mechanical and fully-controlled, it may be ensured, is transcended in aerosol formations where natural forces apply which are outside the range of the same degree of artificial control.

In artificially-formed systems of solid disperse phase it is impracticable, in general, to produce systems whose particles are less than 100 uu diameter owing to recombination due to forces immediately superseding disintegration—W. E. Gibbs (354). It is, therefore, impracticable to form artificial dust systems which can be regarded as colloid systems if the 100 uu limit be observed. But, nevertheless, systems of solid disperse phase due to disintegration are classed as colloidal (aerosolic) dusts in the generally-accepted scheme. But, by superseding the upper limit 100 uu—which may be ensured in completely controlled artificial systems when formed—all the immense and numerous natural systems may be included as colloidal systems, though their end-product in process of time may or may not be a system all of whose disperse particles have become less than 100 uu diameter.

Dusts, therefore, will here be regarded as belonging to that section of the colloidal state named aerosols, and consisting of solid disperse phase in gaseous dispersion medium. They will be derived from natural and mechanical disintegration and dispersion processes. Where mechanically disintegrated, there may be few systems whose particles fall below the 100 uu

maximum range because of the difficulties of dispersing such particles without coalescence. Where naturally disintegrated, it is difficult to decide to what extent particles of less than 100 uu are formed, or what is their origin. Since all smokes and fumes inevitably become dusts finally, by transition, smokes and fumes must be included in any complete survey of dusts, but in natural systems no definite line of demarcation can be drawn since, at any moment, a smoke particle classified as such as a member of a system where the particles are continuously coalescing, may whilst still 100 uu diameter, be removed from the system by wind or convection currents. Such a particle has then become a dust particle. Thus, of all particles in natural dust systems of less than 100 uu, it cannot be said whether they were originally smoke particles or whether, as true dust particles they are the descendants of successive natural disintegration systems, i.e. dust systems.

Whilst the well-known phenomena of light-scattering in the atmosphere, and the stoppage of ultra-violet radiation will be produced, so far as produced by dust, by particles of diameter over 150 uu (the lower wave length limit of the solar spectrum) it is not reasonable to suppose that this figure represents a sudden termination of dust disintegration. From the immense range within which dust particles have been found throughout nature down to 150 uu diameter (smoke or fume particles are of relatively new significance in a geological sense) extrapolation of continuous disintegration and degradation from large rock, soil or other formations, must extend to beyond 100 uu, and there seems no *a priori* reason why it should not extend to, say, 1 uu or molecular dimensions. The finest dusts from deserts and volcanoes are borne to great heights throughout the atmosphere and probably suffer continued and continuing disintegration under atmospheric and diffusion influences, which overbalance the more local effects of brownian movement, ordered settling and aggregation.

In referring to such an immense phenomenon as the dust horizon, Shaw and Owens (130) consider the appropriateness of the term "smoke particle" to be of doubtful significance. But the size of the usual smoke particle may even be regarded as being as little as 200 uu. Just as it has not been practicable to regard 100 uu as an upper particle size limit in the classification of aerosols, such a limit cannot, in natural systems, be

regarded as a lower particle-size limit for dust systems in particular. For the existence of dust systems of all size degrees above 100 uu suggests by extrapolation the existence of such dust systems of all sizes below 100 uu, in the natural condition. This is in line with Arrhenius' suggestion (74) that particles or electrons are shot off at great velocity from the sun, such solar " dust " dividing into two streams directed to the earth's poles, creating atmospheric electricity due to their bombardment of the outer atmosphere ; producing aurora, and nuclei for high cirrus clouds ; and violent electrical fluctuations on the earth. Disintegration and dispersion in nature are, undoubtedly, totally different in process from their mechanical counterparts.

W. E. Gibbs' classification of aerosols may be alternatively stated as: (*a*) dusts—of particle diameter over 10^{-3} cm., which do not diffuse through a porous partitition, and settle with accelerated velocity, (*b*) clouds—of particle diameter 10^{-3} to 10^{-5} cm., which do not diffuse through a porous partition and settle with non-accelerated velocity, and (*c*) smoke particles of diameter 10^{-5} to 10^{-7} cm., which diffuse fairly rapidly through a porous partition and do not settle at all. A wide study of these problems is found in " Clouds and Smokes " (373) by the same author. P. Drinker regards (i) dusts (solid) as of diameter from less than 1 u to 150 u ; (ii) fumes (liquid or solid) from 0·2 u to 1 u diameter ; and (iii) smokes (liquid or solid) of diameter from 0·001 u to 0·1 u. Many other classifications—more or less arbitrary—have been put forward. Thus B. W. Richardson, in 1876, divided dusts into wounding, irritating, inorganic, saline soluble, poisonous organic, and irritant obstructive; Layet classified them as mineral: metallic (non-injurious or poisonous), saline (non-injurious or poisonous) ; vegetable: carbon, cellular or ligneous ; and organic. Heim de Balsac and Agasse-Lafont classified into active and inert ; and Hoffman (1908) made a classification of harmful dusts into vegetable, animal, mineral, metallic and mixed.

Whytlaw-Gray and Patterson's definition of smoke (205) is that of systems consisting of low vapour pressure which settle slowly under gravity, and are formed by chemical processes, electrical or mechanical pulverization, volatilization or combustion. Size limits are not suggested, and if such limits are inapplicable to the more-restricted field of smoke, much more so must they be to the much wider one of dust.

SIZE RANGE OF DUSTS.

It will, therefore, be desirable to take as the size limits of dust, the whole of that range between macroscopic and molecular dimensions. This assigns to many dusts—in common with many smokes—slow settling under gravity. Since most dusts originate from solid bodies they have negligible vapour pressure. Likewise the formation of some dusts is initiated by (natural) chemical processes and others may be formed by electrical or mechanical pulverization. On the large natural scale also, as in volcanic or meteoric action, dusts are the result of volatilization or combustion. If, in these latter cases, smokes are the primary products, this would exemplify on a huge, natural scale, the manner in which smokes culminate as dusts. This close similarity between the characteristics of smokes and many dusts, and their mode of formation, suggests that a more fundamental distinction should be looked for as a means of differentiating between them. This it may seem is best to be found in the existence of a fundamental difference involving the *growth* of the respective systems. Thus, taking a newly-formed smoke system, the system continuously grows, the function of such growth being the increasing size of the disperse particles by agglomeration, as the tendency of their life history. This increasing growth generally also applies to fume particles. Taking a newly-formed dust system, say near the macroscopic limit, geological evidence suggests that the system continuously grows, the function of such growth being the decreasing size of the disperse particles by degradation as the tendency of their life history—Blacktin (355).

Whilst in a dust system the larger the particles the quicker will be their fall under gravity, owing to their density constantly approximating to that of the original solid material, and in a smoke system this will not be the case with growth of particles, the definite reason for this is that the whole system itself is modified in smokes due to particle growth. For, whilst a dust aerosol remains the simple two-phase system that it originally was, a smoke aerosol with growth ceases to be a simple two-phase system in typical cases. Thus, the growing agglomerates of a smoke aerosol themselves become colloidal systems (consisting of a gaseous disperse phase in a solid dispersion medium) enclosed within the prime system. It is this departure from the true, original system which alone

maintains slow settling under gravity, though particle size is continuously increased.

THE SCOPE OF SCIENTIFIC DUST STUDY.

In addition to the—perhaps rather tardy—study of dusts on account of their inclusion as aerosols, a much more powerful stimulus to their scientific study has been promoted by their practical importance in certain directions. This practical importance is due essentially, not to their positive utility or value, but to their operation as a danger and a nuisance. Thus the study of smoke whether by W. E. Gibbs (373), Cohen and Ruston (213), W. J. Russell (374), Des Voeux and Owens (375) in Great Britain; or The Mellon Institute of Industrial Research, Drinker, Thomson and Fichet, etc., in U.S.A., prior to 1924, supplemented by the thorough mathematical preliminary study of Whytlaw-Gray and Patterson (205), up to 1932, has probably been chiefly inculcated by the increasing atmospheric pollution due to the increasing hold of industrial production, and the continued domestic use of raw coal fuel. J. Aitken (28) was the first, in 1880, to investigate the amount of dust in the atmosphere. Dusts, as such, and in particular those which are formed in industrial processes internally (as distinct from those poured externally into the atmosphere) have, as a result of their own definite disease-producing effects given rise to much medico-scientific study in particular directions, and this applies also to the pulmonary effects of atmospheric pollution. Thus, much effort and ingenuity by distinguished medical workers (*cf.* Dust in Physiology, etc.) has been bestowed on the study of such dusts as cause silicosis, asbestosis, grinders' rot, miners' phthsis, and other pneumoconioses.

Whilst the first reliable contribution to atmospheric pollution study dates back to "Fumifugium, or the Smoake of London dissipated" by John Evelyn, in which he offered suggestions for removing fog and smoke, conversing thereon with Charles II in the latter's yacht on the Thames, in 1661—R. B. Pilcher (525)—and which has been recently republished by the National Smoke Abatement Society, Shaw and Owens (130) give their attention to both smoke and dust. Again, W. E. Gibbs (248), P. Beyersdorfer (133), Price and Brown (251), J. Lichtenberger (378) and others are more exclusively concerned with the dangers consequent on that technical production of dusts of

all kinds in industrial technological processes. In whatever direction the field is scanned it is seen that, scientifically, dusts (exclusive of smokes) have been studied negatively in order to avoid their undesirable effects, rather than positively to elucidate their general scientific nature and position. The contrast of this attitude with the probable necessity and importance of dusts for the maintenance of life on the earth (human, animal, vegetable and bacteriologic), and the existence of the staubosphere—coextensive with the atmosphere—make it increasingly surprising that they have not been positively studied. It also creates the necessity to present the scientific exposition of dust studies in a more or less disconnected fashion, due to the isolated aspects which have, so far been studied, although Remy (455) has recently discussed the chemistry of dusts.

Since, in natural smoke formations, e.g. from factory or domestic chimneys, the smoke system is never a self-contained one which can be so studied, but a gradual diffusion into or permeation of an already existent dust system by a liberated smoke, the rate at which the original smoke particles are prevented from continuing as such (i.e. prevented from exercising coalescence to larger units) depends on the equilibrium set up between rate or coalescence in the particular smoke, and rate of diffusion, convection and wind velocity, preventing coalescence. For example, in a high wind, smoke is dispersed to dissemination as an addition to the general staubosphere immediately on issuing into the atmosphere. Although, in practice, a smoke system may persist as such (with constant dimunition) for a considerable time, since it is progressively losing its smoke or coalescence character, it will be convenient to take the limiting case of immediate dispersion as the general case. The addition of all smoke systems to the general atmosphere will, therefore, be regarded as additions to the general staubosphere or atmospheric dust content. If further reason be needed it is that, after complete coalescence all solid smokes necessarily become dusts, and the majority of industrial smokes constantly thus adding to the staubosphere are, in fact, solid smokes.

The first accurate observations of suspended organic matter in air were made in 1885 by W. J. Russell (374) who ignited his glass-wool filter with copper oxide to estimate carbon and nitrogen, and found amounts varying from 0·35 mgm. per 100 cu. ft. in fine weather to 2·44 mgm. per 100 cu. ft. in foggy

weather, whilst in Leeds, Cohen and Ruston (377) found about 1·20 mgm. per 100 cu. ft.

W. N. Hartley and H. Ramage (59) have analytically and spectroscopically examined the composition of atmospheric dust and have found: (1) regular composition of iron, calcium, copper, nickel, potassium and sodium, with small carbonaceous content in dust from rain, hail, sleet and clouds; (2) lime, magnesia, alkalies as chief basic constituents of volcanic dust, with only small proportions of heavy metals; (3) chimney soot of varying compositions, but always containing calcium, manganese, silver, copper, nickel, with rubidium, gallium and thallium always present. Hill (89) has quantitatively determined the dust contents of many different air samples, and Gibbs (379) gives less than 1 mgm. per cubic metre in the country and over the sea; from 1 to 3 mgm. per cubic metre in towns; and up to 5 mgm. per cubic metre in an industrial centre. Delejeune (380) found 6·3 tons deposited in 12 hours in Lille; W. Irwin (381) estimated 30 tons per 100 square miles in and around Manchester; Cohen and Ruston (213) found in Leeds 220 tons per square miles per annum deposited; Des Voeux and Owens (375) found 259 tons per square mile per annum for London; and in the 1932 report of the Committee for Atmospheric Pollution, the amount is given as 61·58 tons per square mile per month. for the heaviest deposit that year at Ashington, Northumberland.

CHAPTER VII

DUST IN EXPERIMENTAL SCIENCES.—CONCLUDED

THE DETERMINATION OF ATMOSPHERIC DUST.

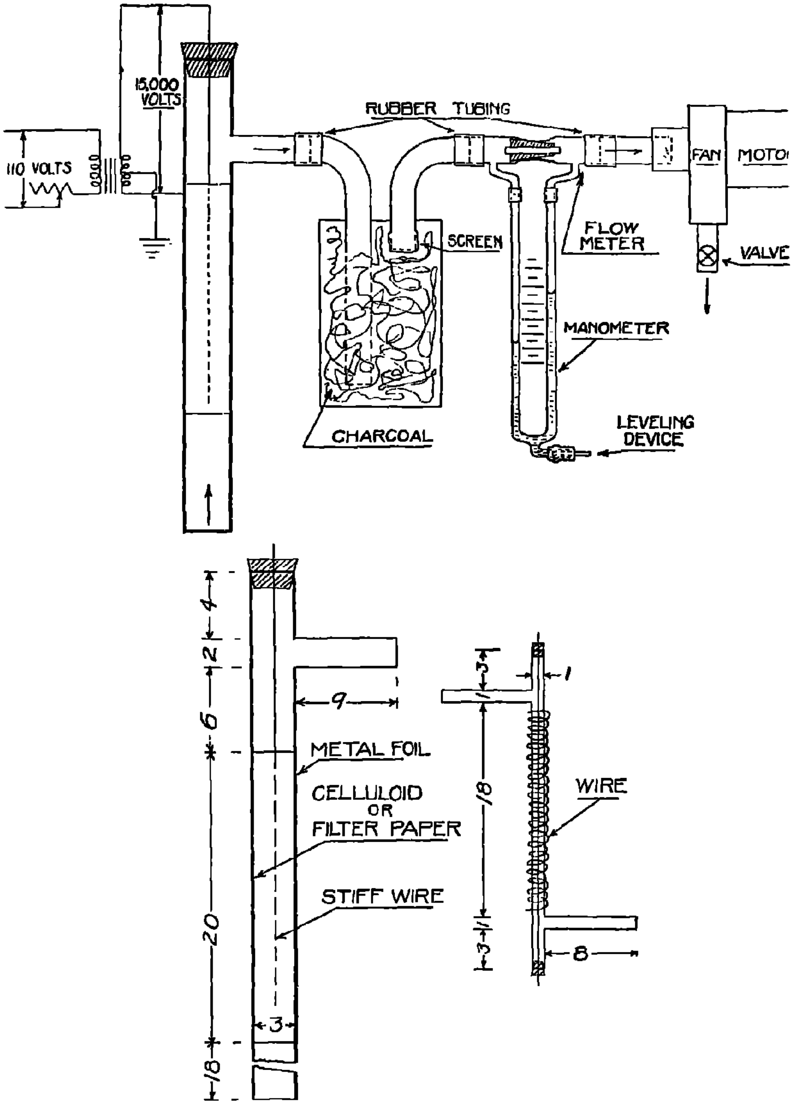
THE original and present means of estimating the amount of solid matter deposited from the atmosphere is the standard gauge in Great Britain. This was invented in furtherance of one of the objects of the Advisory Committee on Atmospheric Pollution to develop standard methods of measurement, the committee itself growing out of the 1912 committee formed under the auspices of the *Lancet* with Sir Napier Shaw as chairman and Dr. J. S. Owens as secretary.

The standard gauge is a circular vessel of approximately 4 sq. ft. catchment area, originally of enamelled cast iron and maintained about 4 ft. above ground level. It carries bottles underneath of capacity sufficient for collecting one month's rain. A bird-screen of wire gauze surrounds the vessel. Finally, a smaller stoneware vessel on a galvanized iron stand replaced the cast iron enamelled one. The catchment area being known, and the amount of solid matter deposited being calculable over a given period, the weight per square mile in tons, or pounds per acre, or grams per square dekametre, could be readily calculated. Grams per square dekametre was found to be most easily visualized as an actual area. Using this instrument the summer deposit is found usually to be less than that in winter. The standard gauge is found to be subject to artificial contamination by boys, blown leaves, etc., whilst in a London gauge an unusual deposit of insoluble matter was due to dust from bursting German bombs. J. B. Cohen (382) suggested as an alternative to the standard gauge, glass plates say, one foot square, placed horizontally, loose deposited matter being washed-off after, say, 3 to 6 months, the gradation of tar deposit underneath being estimated by transmission of a standard light, or by reference to other standards.

In the sootfall studies made in Pittsburgh in 1912-1913,

1923–1924 and 1929–1930, under the direction of W. A. Hamor, assistant director of Mellon Institute of Industrial Research, copper containers (197*c*) were used, about 4 ins. diameter × 10 ins. high, which were easily collected for weighing and analysis of contents. These were used at 12 stations in 1912–1913 and 1923–1924 and at 20 (with 2 at each station) in 1929–1930.

Shaw and Owens (130) from the use of the standard gauge, concluded that whilst rain brings down soluble impurities, it has little or no effect in bringing down insoluble matter or soot, as there was a relation between rainfall and soluble matter, but none between rainfall and insoluble matter. They conclude that the nuclei necessary for raindrop formation does not represent dust as ordinarily understood, since there is a selective action of soluble matter. Once formed, the raindrop projecting before it a moving column of air, will sweep insoluble matter from its path. This view of the deposits carried down by rain should be considered in conjunction with heavy raindrop deposits noticed in very many instances—particularly in thundery weather—by the author on motor-car bodies, dark-painted woodwork and stone pillars. These heavy deposits, which completely define the area of the drop in a very definite manner are, when all water is vaporized, seen to be of a sandy or siliceous nature in certain localities. In this case such drops (they may represent a special type of drop) would have carried down a considerable insoluble content. If soluble, the fall of such drops must have been a constant progression of solution. Of the total dissolved solids gathered by the standard gauge some is considered as true atmospheric content, since dust-free air can only be supposed at extremely high altitudes—Shaw and Owens (130)—whilst undissolved matter consists largely of dust from the ground (which rises to gauge level) and carbonaceous matter. It is found that the dust composition varies from district to district, dependent on geological and surface features, and from town to country dependent on nature of roads and other open spaces. Whilst, in the general use of the gauge soluble and insoluble matter are thus distinguished from the viewpoint of the present monograph all matter collected—including the formation nuclei—represents dust from the staubosphere, since the moisture condensing to form raindrops will, initially, be almost completely pure.



[By courtesy of Dr. Philip Drinker.

FIG. 3.—AN INEXPENSIVE ELECTRICAL PRECIPITATOR UNIT.
The smaller diagram shows the dimensions of the larger scale precipitator tube, and also a smaller tube which may sometimes be conveniently used, though not suitable for accompanying metal or celluloid sheet. Figures represent centimetres.
The charcoal reduces, but does not eliminate damage to rubber stoppers and tubing.
The precipitator tube may have the side arm clamped in a laboratory stand.
The high-voltage transformer—hitherto an expensive item—is now found to be suitably provided by a "luminous-tube transformer" for operating neon signs, at about 8 dollars.

The necessity of using different methods for estimating the suspended solid matter in the atmosphere, as distinct from the deposited solid matter, indicates the existence from this viewpoint of two great divisions of the staubosphere. Thus there is the population of larger particles which settle fairly rapidly under gravity, and that of minute particles which probably largely form a constant floating population. This latter population comes within the settling ambit of Stokes' law when the particles are less than, say, 10^{-2} cm. radius, but the reason is developed later why this minute population must be still further sub-divided into particles which obey Stokes' law (6) and others which obey Cunningham's law (8). The size transition from one class to the other is, of course, gradient, not abrupt. A good idea of the dimension difference and number of units of the two classes of larger and more minute particles is obtained by watching the motes in a sunbeam. These motes represent the larger class, of course, but the apparently clear spaces in between them are filled with the smaller class to as many as 100,000 per c.c., or more, varying with the locality and conditions.

Methods for estimating the total component of the staubosphere are applied either to the determination of (*a*) weight per unit volume, (*b*) number per unit volume, or (*c*) comparison method of discolouration with standardized samples. In making actual tests a combination of (*a*), (*b*) and the size distribution of particles is considered desirable.

J. S. Owens, after considering the various possible methods before the British Association in 1913, finally decided that for (*a*) weight determination, filtration through specially prepared paper was most satisfactory. Previous passing of the dust-laden air through water removed but an inappreciable amount of dust. This confirms the experience of J. Tyndall (383) who passed air through glass wool, acid and alkaline solutions, glass-packed tube and marble-packed tube, successively, without arresting the suspended dust. The pertinency of this to the attempt to industrially arrest dust by water-spraying is very great.

Distinct applications of the above various methods are shown as follows :

(*a*) Weight per Unit Volume Methods.

1. *Air Filtered and Deposit on Filter Weighed.*

In this method, adopted by J. S. Owens, sufficient air is drawn through a special filter paper held in a tubular screw-clip by an aspirator, to form a weighable deposit. Two or three minutes is required to allow for pressure adjustment in the aspirator. The amount of dust deposited in the filter-paper disc must be sufficiently large to allow the weight variation of the paper itself to be regarded as experimental error. For coarse, dry suspensions, say particles of 10 to 80 u, another method is to use paper extraction thimbles, or for such dusts as inorganic mine dusts sugar filters are useful. For particles less than 10 u their efficiency is of the order 70% to 80%. The sugar is dissolved to estimate the dust weight. Tissandier uses asbestos in a U tube for filtration, and Bontemps in 1899 used a U-tube and cotton wool, whilst C. Naeslund (506) in 1932 describes a rapid dust-extracting method using olive-oil-coated glass pellets in a glass tube.

2. *Impurities Washed from Given Air Volume, Weighed and Analyzed.*—This method suffers owing to the great difficulty of extracting all particles and the loss of possible soluble particles. It is represented by Palmer's apparatus wherein air is drawn at high velocity through 40 c.c. water in a special vessel. Particles in 1 c.c. are then counted in a cell after settlement.

(*b*) Number per Unit Volume.

1. *Dust Particles used as Condensation Nuclei, Deposited and Counted by Aitken's or Owen's Method, or Merely Impinged by Kotze Konimeter.*—This has become the standard and widely-used method for counting the number of particles of the staubosphere in a given volume of atmosphere. The original instrument for the purpose was invented by J. Aitken (28) who found that moist air cooled by rapid expansion, generally only condenses to droplets if there are nuclei present and sufficiently high supersaturation. In an appropriate chamber diluted dusty air was humidified by damp blotting paper. The fallen drops were caught on a slide and microscopically computed. This was followed by Owen's jet dust counter ingeniously making use of the same condensation principle and depositing dust from air moving at about 250 metres per second, and the Kotze Konimeter employing a highly-developed impingement

method. There are several other impingement methods, viz. (i) Greenburg-Smith, the sample being blown through a tapered tube on to a wet surface. An efficiency of 93% is claimed and sampling rate can be varied, whilst Drinker, Warren and Hatch (505) have described the characteristics of a modified form for field use; (ii) Glibert's method has been particularly used in linen factories. It essentially consists of impinging particles on a celluloid film coated with sterile gelose. Particle number and shape are microscopically determined, and the discs can be incubated for bacterial estimation. The Gemmy (1927) method utilizes impingement of particles on glass moistened with castor oil. The extension of Owen's dust counter for sampling alveolar air in conjunction with the Haldane extension tube for sampling carbon dioxide in alveolar air should also be noted and the Zeiss Konimeter—the old type embodying the microscope, and the new type being separated therefrom—of 5 c.c. capacity—similar to the Kotze instrument, with a battery of 30 dust spots and giving about 50% higher counts than the latter.

2. *Dust Electrically Deposited and Particles Counted.*—The method of electrical precipitation is receiving increased attention. The Lodge-Cottrell large-scale process for dust and fume recovery is a modification of the laboratory process aimed at counting the particles in a given volume. A high voltage must be employed, which necessitating a transformer or electrical machine militates against the method being used when easy transportation is a necessity. Its effectiveness varies with constructional details of apparatus, rate of operation and voltage employed, though it can be used with fine or coarse suspensions. Of the dust precipitated about 2% is found on the central wire electrode and 98% on the containing tube walls.

3. *Ultra-microscopic Direct Count of Particles in given Volume.*—Even less transportable than the electrical precipitation method. Now, however, that special attention has been given to cell construction by Whytlaw-Gray and Patterson (205) it has decided advantages over (1) and (2) in that the particles to be counted are isolated and, therefore, not appreciably agglomerated, and they are counted in their natural medium without disposition on a support. Disadvantages are that the particles being illuminated, their individual contours are not seen and a very small volume sample is examined at once.

4. *Thermally-Precipitated Direct Microscopic Count of Particles in given Volume.*—A thermal precipitation method based on principles first observed by Coulier and J. Aitken has recently been developed by Whytlaw-Gray and Lomax (205). This method is stated to give counts similar to method 3. Since heat is used its disadvantages are likely to be (i) that hygroscopic nuclei will be unloaded, and therefore (ii) the necessary microscopic counting will miss them. This method is now being tried out (528*a*), and (528) gives counts similar to jet dust counter, giving a count of insoluble particles large enough to be seen under a microscope.

(*c*) COMPARISON METHOD OF DISCOLOURATION WITH STANDARDIZED SAMPLES.

1. *Discolouration on Filter Paper from known Volume of Air Compared with Standards.*—In this method, adopted by J. S. Owens, 2 litres of air are drawn in about 7 minutes by an aspirator through a special filter paper held in a tubular screw-clip. A further 2 or 3 minutes is required to allow for pressure adjustment in the aspirator. The dust deposited in the filter paper disc is compared with calibrated standards.

2. *Discolouration on White Paper from known Volume Air Jet Compared with Standard.*—As it is more convenient to obtain deposits from jets on glass slides so that they may be microscopically examined, this method does not find much use.

3. *Known Length Air Column Compared for Opacity with Standard Light.*—A method more applicable to the finer particles of the staubosphere only, e.g. smoke particles. This is essentially the scattering method of the Tyndallmeter, as used by Tolman, Vliet and others (3), and Tolman, Gerke and others (3), who showed intensity of light reflected by cloud particles $= \frac{R^1 C}{d}$ where $C =$ mass per unit volume of disperse phase, and $d =$ diameter of particles. It is also the basis of delicate developments in a specialized form of photometer, called the Capnometer, described more fully later, and employing a photo-electric cell, and the amplification and galvanometric measurement of the feeble currents due to varying intensities of particle populations in the atmosphere, etc. On the large scale a method on these lines has been used for study-

ing smoke densities in vehicular tunnels. In addition to the Tyndallmeter the Contrast Photometer has been used by J. S. Owens for determining the obstruction of light by dust in air as an estimate of atmospheric pollution. Owing to colour, size, shape and refractive index of particles these photometric methods are only sufficiently accurate over a narrow field of dust concentration. Seitz—1927—has used a method of photographic comparison and standardization applicable to metallic and inorganic dusts. Standard metallic dust plates (celluloid) photographs, carrying 5 to 10 mgm. of dust are prepared in the laboratory. On similar plates, paraffin or albumin-glycerin coated factory samples are caught. Comparison with the standards is then made. Lovibond (90*a*) has developed a light-stopping method of smoke estimation.

4. *Visibility of Objects at Fixed Distances Noted and Compared from Time to Time.*—This is a large-scale empirical method which does not lend itself to laboratory or small-scale determinations of the staubosphere. It was used on a field-scale during the War of 1914 to 1918 as an approximate means of comparing smoke intensities in clouds, by reference to the absorbing effect on light from a standard electric lamp.

A method for estimating the coarse dust complement of the staubosphere only is J. S. Owens' settlement dust counter. This he invented to estimate those particles which are so large as to be prevented from passing the slot of the jet dust counter. It consists of a metal tube of known volume, closed at the top, and carrying an adjustable glass slide at the bottom. The coarse dust from the given air volume is allowed to completely settle on the slide, which is then microscopically examined and the particles counted. Great care must be bestowed on the pre-cleaning of the slide, and great pains and special precautions are generally necessary to ensure its complete initial microscopic freedom from extraneous dust particles. Sutherland (22) points out that size of microscopic particles from 10^{-2} to 10^{-4} cm. can be found by noting settling speed under Stokes' law (6).

Of the above methods of computing the total staubosphere, those in most general use are (*a*) (1) and (*c*) (1) filtration methods for estimation, respectively, by weight and comparison with standard, and (*b*) (1)—glass slide deposition method—for estimating number per unit volume by either Aitken's counter, Owens' jet dust counter, or the Kotze Konimeter. Of these

three instruments, probably Owens' jet dust counter is most widely used in England and America, though the Kotze Konimeter finds much use in South Africa (the country of its origin) in connection with quartz dust measurement in the gold mines. The filtration methods have been sufficiently described for the purpose of this monograph, but it should be stated that J. S. Owens uses (*a*) (1) and (*c*) (1) in conjunction with two special type gas meters (replacing aspirators)—of much larger capacity for (*a*) (1) than (*c*) (1)—and gets a weight record and comparison record simultaneously for the air tested (130).

For large-scale or field work at stations where personal attention is not constantly available, an automatic recorder has been adopted which, over a period of about 24 days, gives a succession of filtration comparison records on a special filter-paper disc, which can be compared for statistics and kept for record.

The Owens jet dust counter will be shortly described as typical of the condensation deposition method—(*b*) (1)—though the other instruments of Aitken (28, 29) and Kotze (88) have very distinct technical differences, the former being based on the principle of condensation, the latter on that of impingement of 5 c.c. of dust-laden air sucked through an inlet nozzle 0·8 mm. bore on to a vaselined glass slide, producing a dust record of less than 1 mm. diameter, the slide carrying six to twelve successive samples (invented by R. N. Kotze of South African Mines Department).

The essential principle of the jet dust counter is the condensation of moisture from a saturated atmosphere on to the units of the contained staubosphere as a result of an adiabatic expansion. There is doubt as to which component of the staubosphere, i.e. hygroscopic nuclei, or insoluble particles, first receive condensation. An open cylindrical metal chamber of 50 c.c. capacity lined with damp blotting paper holds the sample of air or gas to be examined. A hand pump of similar capacity is connected at right angles to this chamber, and between the two is a small communicating metal cell containing a metal platform which holds a microscope cover glass (or paper disc, if required) about 1 mm. from a slit in the base of the damping chamber, the slit being 1 cm. long and 1 mm. wide. On sharply operating the pump, moisture and particles are projected through the slit, the moisture adiabatically condensing on to the particles, and the particles being projected on to the

cover glass, giving a slit image or ribbon consisting of the staubosphere of the 50 c.c. capacity chamber. With a 1/12 in. objective, the particles in a measured section of the slit can be counted, and the number of particles in 50 c.c. of air (or gas) thus be readily calculated.

For further descriptions of a number of methods, the *Journal of Industrial Hygiene* (384) should be consulted, as well as Shaw and Owens (130). A disadvantage of Aitken's (28, 29) apparatus advanced by Owens is that it does not distinguish between dust particles and other nuclei. This seems to imply that dust is some arbitrary division of the staubosphere, and that an estimation of the dust population is not required to be an estimation of the total suspended population. On the other hand, Aitken's dust counter is regarded as taking count of hygroscopic nuclei from the atmosphere—Boylan (385) and Wigand (386), though Whytlaw-Gray and Patterson (205), from more recent experiments by Lomax, concluded that Aitken counts agree closely with those of the ultra-microscope even in the absence of hygroscopic nuclei and with artificially-polluted air. If the ultra-microscopic method developed by Nonhebel and others (475), and Patterson, Whytlaw-Gray and Cawood (476) be regarded as one of two satisfactory ones for estimating particle numbers in smokes, then the Aitken's method giving similar counts under similar conditions must, by analogy, be regarded as a third. Whilst on true hygroscopic nuclei condensation can occur when supersaturation is but 75% normal, and dust particles which are hygroscopic can act like true hygroscopic nuclei in causing condensation, such dust particles as reject moisture are not likely—save, perhaps, under very high supersaturation—to act as nuclei. But remembering the exceeding minuteness of the majority of atmospheric dust particles ; the impracticability of determining what percentage is hygroscopic ; and the difficulty of delimiting dusts, the evidence is as yet perhaps hardly sufficiently strong to regard almost all "dust" particles as other than capable of forming condensation centres.

THE HYGROSCOPICITY OF DUST.

It is desirable to note that since selectivity regarding wetting by water is now considered to depend on the sign of the electrical charge carried by a particle, whether a particle can promote condensation or not, may have still less to do with its chemical

nature (i.e. whether chemically hygroscopic or non-hygroscopic) than even when condensation is regarded as a surface effect alone—without considering concomitant electrification. But, as suggested by the work of Shaw and Jex (167) on surface electrification, condensation may depend on the adsorbed film a particle is almost certain to be carrying. Again, P. A. Mainstone (415) has shown that only at the lowest surrounding gas pressure was the charge characteristic of the rubbing surfaces, when frictional charges were produced by rubbing metal surfaces, a variation of charge with gas pressure being noted. It must, therefore, be regarded as a strong possibility that even "hygroscopic nuclei" of, say, chlorides of sodium and magnesium, or sulphates, are not necessarily hygroscopic in effect—promoting water condensation—whereas non-hygroscopic dust particles may promote condensation by virtue of their adsorbed films. A practical instance of this may be the contrast of moisture absorption of ammonium chloride particles volatilised into normal dust-free air, with its lack on volatilising into air of slight ammonia content. The resultant particle films would differ in the two cases.

The definition of dust adopted for this work as all gaseous suspended solid matter between macroscopic and molecular dimensions, necessarily includes hygroscopic nuclei, so that an instrument which gave a true higher count would necessarily be regarded as more efficient.

Discussion and Comparison of Various Dust Determination Methods.

Whilst the results obtained by the ultra-microscopic method were in 1925 not satisfactory, since they were always less than the number registered by the jet dust counter, this was due to the design of cell—3·5 mm. deep which was altogether too great for the depth of focus of a high-power objective, and necessitated the use of a 2/3 in. objective—whilst a 1/12 in. objective was used for jet dust counter record counting. Thus Owens states that on December 1st, 1921, a jet record gave a count of 11,300 particles per c.c., and an ultra-microscopic count but 4,400 per c.c. But Cohen and Ruston (213) consider Owens' jet dust counter to give results much lower than those recorded by Aitken's dust counter, in addition to its being less compact and convenient. If, therefore, Aitken's method and the improved ultra-microscopic method give

similar results (205), the improvement in ultra-microscopic technique now allows it to give higher—not lower—results than Owens' jet dust counter.

The electrical precipitation method for dust counting must also be considered. It seems to have been first used by Drinker, Thomson and Fichet (288). As a dust *remover*, however, electrical precipitation was first suggested by Hohlfeld—1824—as a means of preventing smoke nuisance, and was followed up more fully by O. Lodge (21) in 1883 with the consequent production on the commercial scale of the Lodge-Cottrell precipitation method (*cf.* Dust in Industry and Technology). In principle the commercial method is identical with that of the counting method. Drinker, Thomson and Fichet (288) used unrectified A.C., at voltages of 1,000 to 20,000, and Drinker, Hazard and Ishikawa (509) describe an inexpensive unit on these lines for sanitary air analysis. (Fig. 3.)

Tolman and others (3) and Lamb, Wendt and Wilson (4) also developed laboratory electrical precipitation methods, whilst Strong (5) took out a U.S. patent for electrical precipitation on moving paper, and Rohmann (477) developed a size distribution method for fine dusts dependent on the precipitation of fully-charged particles by an electric field.

Aitken (28, 29) found that rooms contain the greatest number of dust particles; that, in the open, they diminish in number after rain; are more numerous at higher than at lower altitudes; and more numerous in dry town air than in the country. Figures which he determined with his apparatus are shown in the following table appearing in " Nature " (478).

TABLE III

SOME OF AITKEN'S COUNTS OF DUST PARTICLES IN AIR.

Occurrence.	*No. of particles per cubic cm.*
Outside air—raining	32,000
Outside air—fair	130,000
Room air—gas burning—4 ft. from floor	1,860,000
Room air—gas burning—near ceiling .	5,420,000
Air above bunsen flame	30,000,000

Aitken also recorded (479) 205 to 4,000 particles per c.c., on the shore of Loch Linnhe, 335 to 473 per c.c. at the summit

of Ben Nevis, and hundreds of thousand per c.c. in London and Paris.

An outstanding feature of the ultra-microscopic method is obviously that the particles are counted in their natural medium without support. Thus, even such superposition of individual particles as may occur in electrical precipitation will be mostly absent in the ultra-microscopic method, whilst the opportunities of superposition and agglomeration on the Owens' ribbon record are obviously tremendously magnified. Whether the great difference between jet dust counter results on the one hand and Aitken's and the ultra-microscopic methods on the other, is solely due to particle agglomeration in the former case, is difficult to say, but since the jet dust counter record is not likely to give account of hygroscopic nuclei, Aitken's method on the other hand undoubtedly does. If the aggregates—admittedly obtained on the jet dust counter record—were already pre-existent as aggregates in the air, then the lower jet dust counter figures in such cases, give a truer value for the actual staubosphere than the ultra-microscopic, Aitken's, or the electrical precipitation methods. And whilst it is conceivable that the staubospheric aggregates are split-up by electrical precipitation thus giving a too high count, this can hardly occur on gentle suction into the ultra-microscope cell.

Of the four methods it may be suggested that the ultra-microscope and Aitken's are those most likely to give account of the hygroscopic nuclei, since with the former the air first passes through a moistened tube and then into a moist cell, whilst any condensation drops consequently formed are much more likely to retain their respective nuclei as separate units, than in either the jet dust counter or electrical precipitation methods. But adiabatic expansion is not applied in the ultra-microscopic method to load up the nuclei. Whilst, therefore, many drops, rather than solid particles as such, may be counted in the ultra-microscope cell (the loss of particle contour making particles and drops indistinguishable) it must be remembered that all drops represent particles in the shape of hygroscopic nuclei.

The question, therefore, again arises in deciding which of these methods gives the truest record of the staubosphere, whether hygroscopic nuclei are to be included as dust. In this monograph such inclusion must be adopted. C. Barus (536),

who over some years found 2,000 to 100,000 nuclei per c.c., produced by various means such as chemical activity, evaporation, violent agitation, considers nuclei as dust particles greater than molecular dimension. He found their number greatest in December and least in June with great day-to-day variation.

The principle of thermal precipitation originally observed by Coulier (480) and later by Aitken (51) has been used recently by Lomax for measuring dust content of air as a refinement and extension of the method of sedimentation on glass slides from a long column of air—which usually gives a sparse deposit examined with difficulty. Thus Lomax (205) passed air between two parallel plates, the lower of which is covered with a glass slip and kept cool, and the upper one heated to about 110 degrees centigrade. Particles contained are thereby repelled from the upper and precipitated on the lower plate. The precipitated particles are observed and counted microscopically. It would seem that the temperature gradient imposed in the thermal method would be a condition calculated more than any other, to prevent condensation of moisture on nuclei in the air examined. Since further, counting must be done microscopically, with a visibility limit of 0·2 u, dry nuclei of less than 0·1 u diameter would be unobserved and uncounted as individuals, and perhaps even if agglomerated. But if in such a nuclei-ignoring method counts were comparable with those of the ultra-microscope, this would suggest that ultra-microscopic counts take no account of hygroscopic nuclei, or else that the ultra-microscopic method misses the grosser particles probably counted by thermal precipitation. These suggested limitations of the thermal method seem confirmed by the conclusion since published that it gives counts of jet-dust-counter order the latter, by analogy, giving an estimate of the insoluble particle number large enough to be seen by a microscope, in the air (528). Supposing that the lower visibility limit in the ultra-microscopic cell is $0{\cdot}5 \times 10^{-6}$ cm. radius, if nuclei are not counted it is probably because they are of less dimension than this. The nuclei here referred to are unattached hygroscopic soluble units, and not smoke nor other particles acting as hygroscopic nuclei. According to H. L. Green (387) in supersatured air larger particles are first condensed on, and perhaps the simple suction of particles through a damp tube will not be sufficient to load the nuclei. But even so and if unloaded, if of $0{\cdot}5 \times 10^{-6}$ cm. radius, they

should be countable in the ultra-microscopic cell. If not counted, then the difference in counts of the jet dust counter, and the ultra-microscope must be solely due to agglomeration.

Agglomeration by the electrical precipitation method is suggested as a possibility by Whytlaw-Gray and Patterson (205). If, as seems to be indicated above, the ultra-microscopic method does not count the nuclei, and these are less than $0 \cdot 5 \times 10^{-6}$ cm. radius, then according to Gibbs aerosol classification, dusts having a lower limit of 10^{-5} cm. hygroscopic nuclei must, according to that classification, be classed as smokes. But this can only be so as regards particle size, their general behaviour, except where smoke particles act as nuclei—Green (387)—being probably dissimilar from that of smoke particles, whilst if the lower size limit of dusts be extended below 10^{-5} cm., such nuclei may equally be dusts. And eventually all smokes become dusts, either after agglomeration or due to leaving the smoke system before agglomeration. Shaw and Owens (130) give the size of the ordinary atmospheric smoke particle as about 0·5 u, which will not freely exhibit brownian movement if the upper readily-observed limit of brownian movement be 10^{-5} cm. (i.e. 0·1 u). But an objection to ultra-microscopic records previous to 1925 was that the particles exhibited brownian movement which obviated making a good count. Such particles must, therefore, have been probably less than 0·1 u. It seems plain, therefore, that the jet dust counter may not be calculated to give counts of anything much less than 0·5 u, whereas the ultra-microscopic method obviously takes full account of particles even less than 0·1 u.

The probability is, therefore, that the ultra-microscope and Aitken's method give counts over very wide field limits; electrical precipitation over a less-wide size limit field due to some agglomeration; and the jet dust counter over a still more restricted field. These differences seem to be due not to the principles involved respectively—for the jet dust counter will, before precipitation, tend to load up the hygroscopic nuclei more effectively than the ultra-microscope as used—but to the respective modes in which the particles are placed on record. Again, in electrical precipitation moisture is not elaborately introduced, as in the other two cases, so that the majority of hygroscopic nuclei escape loading. In thermal precipitation the nuclei will not merely tend not to be loaded,

but will, presumably, be definitely prevented from loading on account of the hot plate at 110 degrees C. Since nuclei will be mostly less than 0·1 u radius, and the lower limit of microscopic visibility is 0·2 u, the nuclei will not be counted under the microscope in either the electrical precipitation, the thermal precipitation, or the jet dust counter methods. Allowing for some agglomeration in the foremost, any difference between electrical precipitation and ultra-microscopic counts of similar samples could probably be regarded as the number of hygroscopic nuclei in the air sampled. Particularly as ultra-microscopic and Aitken-method counts are similar, and the latter method is accepted as taking count of hygroscopic nuclei.

The low counts of the jet dust counter, as compared with both ultra-microscopic and Aitken's methods, suggest that the identity of all hygroscopic nuclei is completely destroyed in making the jet dust counter records, although the loading itself of nuclei is likely to be very efficient in this method. And this view is confirmed by the claim for the jet dust counter —Shaw and Owens (130)—that all moisture vaporises and leaves the record dry, whence, even if nuclei were deposited unagglomerated, since they are less than 0·1 u and lower limit of microscopic visibility is 0·2 u, they will not be counted.

It would appear, therefore, that the decision as to which method provides the most accurate means of counting the staubosphere does not depend on the methods themselves (since they are not strictly comparable), but on the definition of the field covered by "dust," "atmospheric pollution," etc. Of the three methods discussed, the jet dust counter is eminently more portable and mobile than the others, and the counts it gives seem to be representative and proportionate of the higher counting methods. Cohen and Ruston (213), as previously noted, consider the jet dust counter not to be so compact nor convenient as Aitken's apparatus, and that the former gives results which are much lower than those recorded by Aitken's dust counter. They state "this has been attributed to the deposit of drops on electrically charged gases, which would therefore be included among the solid particles." "On the other hand, in the method of counting visible particles on a glass slip even under a powerful microscope, ultra-microscopic particles might well be overlooked." In this view electrically charged gases take the place of nuclei of condensation, but according to C. T. R. Wilson's work (1), only for very high

supersaturation does condensation on ions occur. Again, P. Drinker (196) considers that the jet dust counter is more sensitive than the Kotze Konimeter, and that neither is reliable when dust clouds are dense enough to produce "ribbons" or "spots," since individual particles are then piled up and indistinguishable. He considers these methods could be modified in very dusty air.

Tests of various instruments for determining atmospheric dusts have been compiled and published by S. H. Katz, G. W. Smith, W. M. Myers, L. J. Trostel, M. Ingels, and L. Greenburg (388), and the great South African use of the Kotze Konimeter is dealt with by A. Mavrogordato (389).

The ultra-microscopic method used by R. Whytlaw-Gray and H. S. Patterson (205) was gradually improved by them for the counting of various kinds of smoke particles. Qualitative use of the ultra-microscope for examining small particles was first employed by de Broglie (20) and Ehrenhaft, for photographic record of smoke particle movement—allowing simultaneous observation of size and number—the particles actually measured varying from 5×10^{-6} to 1×10^{-4} cm. diameter. Whilst Wells and Gerke (18) used the ultra-microscope for size determination of Tolman's smokes. Whytlaw-Gray, Speakman and Campbell (390) first made definite ultra-microscopic counts with a Zsigmondy slit ultra-microscope, but finding errors introduced by the slit method—whose use for smoke examination was referred to by King (71)—correction thereof was later attempted by varying the type of smoke cell, and by applying adiabatic condensation—H. L. Green (387)—on particles, which, by increasing their effective size, minimised uneven light-scattering previously following on coagulation. These modifications had limitations which were overcome by the design and use of a completely new type of cell. This cell, which is essentially two optically-ground glass plates, gives, when assembled, a cell depth of 0·1 mm. between parallel faces about 2 mm. wide. In use, a suitable liquid film, such as quinoline or paraffin, covers the parallel surfaces, absorbing particles which strike them (though an inappreciable number is lost), and increasing particle size (with certain liquids) by condensation thereon. By means of an aspirator working through an alternatively opening and closing tap, revolved by a fractional horse-power motor, suction of the particle stream through the cell is intermittent, and the periods

of alternate suction and quiescence can be regulated by a resistance in series with the motor. Degree of suction can be varied by means of a suitably placed needle valve, and the particle stream enters the cell through a narrow glass tube moistened internally (with damped blotting paper) to load up with moisture particles which might otherwise be invisible. The illuminating beam is focussed into the cell from 5 or 10 amp. automatic Zeiss arc carbons through a water-cooled slit, adjustable lens, second slit, and illuminating holoscopic objective of numerical aperture 0·3. The particles are viewed through objectives varying from 50 to 16 mm. focal length, and various eyepieces of varying-sized square diaphragm, the depth of focus of the combination being always greater than 0·1 mm. The illuminating beam must fill the cell field, and particles appear intensely bright against a dark background. The diaphragm area and cell depth being known, the number of particles per cubic centimetre can be computed from the average field count. A count is taken at each quiescent period when *the illuminated particles are momentarily motionless in* the field. The diaphragm size should be chosen to give two or three particles per field on any given occasion, so that counting is coincident with observation.

With this apparatus, described in full detail by Whytlaw-Gray and Patterson (205), the coagulation and life history of many smokes have been studied, practically all of which continue to grow to large aggregates of varying shape and condition, and generally less effective density than the original smoke particles, before they become completely sedimented. The size range of the smoke particles studied in such an ultra-microscope is of the order of from 0·08 u to 0·80 u, so that the apparatus should be very suitable for examining staubosphere particles, many of which fall within the same range. Whilst with smoke particles, however, continuingly increasing coagulation is observable up to agglomerate sizes of, say, in the case of cadmium oxide, 10 u, no coagulation is likely to be observed with staubospheric particles, but rather mutual repulsion. On the other hand, smoke particles cannot be examined immediately on formation, so that a certain degree of pre-coagulation will have occurred. Whilst, therefore, dust particles would doubtless be seen the same size as they were immediately before entering the ultra-microscope cell, smoke particles have in general been much smaller than their first measured size.

Smoke particles have been sedimented on to a clean glass microscope slide, immersed in the smoke system for a few minutes, as a means of examining a smoke sample at any given period—Patterson, Whytlaw-Gray and Cawood (391). Such particles (which when examined will, of course, have ceased to be typical smoke particles and have become dust particles) were examined with darkground illumination or in green or bluish light.

G. St. J. Perrott and S. P. Kinney (392) have developed a microscopic method of measuring particle thicknesses, and H. Green (393) describes the microphotographical measurement of fine particles, whilst Feret (394) deals with the grading of powdered particles, and H. L. Green (539) gives methods of dust particle number and size-frequency determination.

A method for determining the distribution of particle size in a dust sample is described by W. J. Kelly (395) depending on the observation of fall in hydrostatic pressure of a settling suspension in a glass tube at a given level. G. Wiegner (396) also describes a method of suspension analysis. Various methods for estimating smokes are given by Smyth (91), Palmer and others (92), and Boyd (93). Kershaw (94) gives methods employed by the Hamburg Smoke Abatement Society, and Thomson (95) used a method of staining paper on a water-cooled drum, patented by Eddy in 1910. Lamb (422) discusses a portable electric filter for smoke and gases; Wells (423), an oxidation method for measuring ultra-microscopic particle size; Drinker and others (193), photometric methods for estimating suspensions of dusts, fumes and smokes; Katz and others (424), the efficiency of the Palmer apparatus for air-dust determination; Drinker (425), the use of electrostatic precipitation and Owens' jet dust counter in dust determination; Pigulewsky, the use of a bilateral rheometer for air-dust content determination; D. E. Cummings (426), a method of particulate matter separation below 50 micron; E. J. Dunn (427), the determination of pigment and powder particle size by microscopic measurement; Work (428), methods of grading particles; W. Blinow (429), an electric filter method of air-dust determination; S. W. Miller (430), a method of quantitative determination of dust in air; A. W. Simm and others (431), a recording dust concentration meter and its application to the blast furnace; D'Arsonval and Bordas (432) have studied determination of dust in the atmosphere; Burstein

(433) considers the determination of dusts inhaled by workmen, and an improved form of his apparatus for determining air-dust ; Z. Pick and W. Broumstein (434) and E. A. Vigdortschik have studied the determination of air-dust content generally, and in work places by Owens' jet dust counter ; M. Kagan and W. Broumstein (436) have advanced a rational method for calculating records of Owens' jet dust counter ; Kozlyaev (512) has made a comparative study of dust filters ; and Carphine has produced a method of measuring dust particle size, used by Khokhryakov in his work on microchemical methods for estimating industrial lead dusts, and Sven Oden has produced by use of an automatic balance, distribution curves for clay particles of different sizes. (Proc., Roy., Soc., 1924.)

The Owens jet dust counter with the glass circle replaced by a paper disc may be used for measuring weight concentration of coloured smokes, but this method has a large error limit, and a better method is to draw a small volume through a small filter weighed before and after on a microbalance.

The pore diameters of various filtering materials are given—J. Eggert (397)—as filter papers $0{\cdot}5 \times 10^{-3}$ cm. to 10^{-4} cm. ; stoneware, 10^{-5} cm., and ultra-filter 10^{-6} cm., and this affords a transient means of estimating particle size. In testing his filter paper filtration method for efficiency, J. S. Owens used two clean discs in contact, and if no deposit were formed on the under disc, the upper one was regarded as having extracted all solid impurity from air or gas passing through. Whilst this would at first seem to be a just conclusion, on examination it seems that as the larger particles in the van of the incident air column would reduce the effective size of the pores of the upper disc immediately—the effective pore size of the under disc remaining unchanged—any particles which now passed through the pores of the upper disc would yet more easily pass through those of the under disc. This effect would be cumulative whilst the upper disc became more permeated with particles, so that finally only particles which would readily pass through the under disc would, with difficulty, pass through the upper disc. A more efficient way of making the test might therefore seem to be that of placing a partly contaminated disc under a clean one, and observing whether the contaminated disc collected particles which had passed through the clean one.

Optical methods of measuring smokes which might also be applicable to the measurement of the staubosphere as such,

when of sufficient density, or if involved as fog or mist formation, extend from arbitrary methods to those of considerable precision. Thus, during the Great War, obscuring power was represented as square feet of landscape obscured by 1 lb. of smoke material, obscuration being $\frac{V}{D}$ where $V =$ volume of smoke layer, $D =$ depth of smoke to obscure 40-watt lamp. Tolman, Vliet and others (3) used the Tyndall effect, and telescopically examining the emergent light beam from the smoke, found the particle size of the disperse phase (i.e. particles) inversely proportional to the intensity of the emergent beam. Their uniform results were compared with a calibrated scale obtained from finely-ground silica in water. They found that results varied with similar concentrations of smokes due to change in particle numbers, and thus were the first to point out the coagulation effect in smoke systems. A smoke recorder which operates by impingement of smoke on a revolving water-cooled drum has been used—J. N. Friend (188).

In various forms the photometric principle has been used for determining smoke concentrations, and has led to the increasing recent adoption of photoelectric photometry, outlined by J. W. T. Walsh (398), made possible by the joint application of photoelectric and thermionic principles. In this delicate instrumental system, which can be used to almost any degree of accuracy, either a smoke can be used to test the filtering efficiency of any given material, or the concentration of any given smoke or cloud can be tested with reference to standard conditions. British work is now progressing on a photoelectric method for optical intensity measurement of chimney smokes (528).

Recent Advances in Relative Smoke Measurement.

This photoelectric photometric system has been adapted to the study of the effects of atmospheric conditions on the distribution of solids after their emission from chimney stacks and other sources by the Mellon Institute of Industrial Research, Pittsburgh. H. B. Meller (197*e*) states that in conjunction with Westinghouse Research laboratories, a short-range combination for night or day work operating independently from all light sources except that under control has been developed. This

particular type has been named the Capnometer (Greek, capnos —smoke ; metron—measure) by W. A. Hamor, and laboratory tests indicate its future potentialities in providing data concerning precipitation, wind velocities, etc., and in the general study of capnometry—smoke measurement. Dusts in an air-tight chamber, and under control as regards quantities and varieties, have been studied by means of the photoelectric method and the spectrograph (197*f*).

If the photoelectric film of the cell be of uranium, then photosensitivity provokes electrical response only from incident light of wavelength approximately 2,700 angstrom units to 3,350 angstrom units, i.e. in the ultra-violet. This modification has been embodied in the Rentschler ultra-violet meter, and more recently, Rentschler has developed a titanium photoelectric cell (472). This modification, and the uranium cell, have been adapted by the Mellon Institute as an integrating ultra-violet meter for comparing ultra-violet radiation received at Pittsburgh under many differing external conditions, and at all seasons of the year. Work is still proceeding, and a detailed description of the instrument and preliminary results and experimental details have been given by Meller, Hibben and Warga (197*g*) and Meller and Warga (197*h*), respectively. In operation, the instrument is fixed on the roof of the City-County Building in Pittsburgh, 163 ft. above street level, on a turntable making one revolution per day by reduction through gears, from a one-fifth horse power synchronous motor of 1,800 r.p.m. The table (and instrument) are set at an angle of 40 degrees 30 minutes—the latitude of Pittsburgh—the cradle holding the meter having an adjustment for declination. The cathode of the photo-cell—the latter enclosed by a 5-in. corex glass bulb, inside frosted, in turn sealed to a bakelite box fitting the meter tightly to insulate, and retain weather tightness—is thus kept normal to the sun. Without special protection considerable electrical leakage due to dust and moisture was experienced. Each fresh cell must be calibrated against a standard tungsten ribbon lamp of true temperature 2,800 degrees K. The current initiated in the cell by the incident ultra-violet radiation is amplified, and trickles into a condenser of 0·0015 mfd. which, when fully charged, spills over, passing an impulse which operates a Westinghouse watt-hour demand meter with chart—the pen tripping at five-minute intervals. Each line on the chart, therefore, represents

the number of impulses transmitted in five minutes, corresponding to the amount of ultra-violet radiation received in the cell in any particular five-minute period. Very obviously, by using standard sources of light under artificial control, the system can be adapted for laboratory comparisons of smoke or dust intensity.

Burton (26) has weighed suspended particles by applying a vertical electrical field, conferring a particle velocity greater than that due to gravity or brownian movement and applying Stokes' law (6) to the difference between upward and downward movement. Millikan (27) can use his oil drop method for weighing particles by solving for *mg.*, the drop equilibrium equation between gravity and a vertical electric field. Young (72) devised an apparatus for measuring particle diameters on the principle that the angular diameter of halos round a light source is proportional to the size of the particles through which the light is observed, and von Hevesey (73) showed that particle diameter could be found from the expression:

$$\frac{Xe}{3\pi n d} = v \text{ when } v \text{ is velocity due to a field of } X \text{ volts per cm.}$$

A practical device often used for the rough measurement of smoke and dust concentration in boiler flues and chimney stacks is that of drawing smoke by aspiration at about one litre a minute through a 3-in. slit in a tube introduced through a stack wall into the interior at right angles to the stack plane. The smoke and grit are drawn through cotton or glass wool, which is dried to constant weight before and after exposure, the particles deposited being estimated gravimetrically, and the smoke volume from which they are derived being known. But C. E. Prince, lecturing before the Junior Institute of Engineers, now describes the application of the photoelectric method to chimney smoke measurement. The principle is that previously described, the interruption of light by the particles of carbon in the smoke being used to give a continuous, quantitative record. The difficulty arises of chosing a suitable column-length unit, but the method is regarded as being important for testing the smoke emitted from industrial chimneys. At the National Physical Laboratory a daylight recording instrument, giving comparable results with a photoelectric recorder, is being developed (528).

Laws Governing Dust Settlement, and their Implications.

As previously noted, by producing an "imitation atmosphere," Perrin (17) was able to demonstrate with his "giant molecules" of spherical gamboge particles the hypsometric law of Halley—1686—and Laplace, and the work of Torricelli and Pascal, in explaining barometric change with height above sea level, in terms of variation of number of molecules with height. Thus, Halley's law showed that at a height of 6 kilometre above the earth, the number of molecules is halved, from the formula:

$$h = \frac{RT}{Mg} \log_e 2, \text{ where } T = \text{absolute temperature.}$$

Perrin's gamboge particles were produced from precipitation of an alcoholic solution, centrifuged, and being practically all of approximate radius $2{\cdot}1 \times 10^{-5}$ cm., he microscopically examined their vertical distribution in a cell. Whilst he thus used fine particles to determine the avogadro constant, N, the present importance of his work is that he showed particle distribution in the staubosphere, for the size used, to be similar to molecular distribution in the atmosphere, i.e. varying inversely with height above the earth's surface. G. G. Stokes —1850—produced his well-known formula governing the rate of fall—after attainment of terminal velocity when acceleration is zero—of small particles, viz.:

$F = 6\ \pi\ n\ r\ v$, where $F =$ force, $n =$ viscosity of medium, $v =$ velocity, and $r =$ particle radius; and:

$$F = m\ g = \frac{4}{3}\ \pi\ r^3\ (a - a^1)\ g, \text{ where } a = \text{density of particle,}$$

$a^1 =$ density of medium, and $m =$ mass of particle; giving on combining:

$$r^2 = \frac{9\ n\ v}{2a\ \ g} \quad . \ . \ . \ . \text{ Stokes' law.}$$

Stokes' formula applies, when air is the medium, and a^1 is almost negligible, only to particles where r (radius) lies between, say, 10^{-2} cm. and 10^{-4} cm. For, when r is greater than 10^{-2} cm., the acceleration due to gravity does not become zero, whilst when r is less than 10^{-4} cm., the mean free path of air molecules of the order 10^{-5} cm. is too closely approached, and

the medium commences to become discontinuous with respect to particles of that size or less, hence, under brownian movement, the mobility of the particles considerably increases. The stratification of dust particles shown to exist in the air by Perrin's gamboge particles of $2 \cdot 1 \times 10^{-5}$ cm. radius, therefore refers to a size-field in the staubosphere which is not governed by Stokes' law. In such cases where the particle radius approaches the mean free path length of the molecules of the dispersion medium, Cunningham (8) and Millikan (9) have introduced a further factor into Stokes' law, viz. :

$A\dfrac{L}{r}$, where $A =$ constant, $L =$ mean free path of molecules,

and $r =$ particle radius.

Millikan (10) and Cunningham (12) have further shown that $A\dfrac{L}{r}$ holds good for spherical particles moving in air for large variations of $\dfrac{L}{r}$. Whilst A may vary within small limits as $\dfrac{L}{r}$ changes, it may be taken as $0 \cdot 9$ for particles of, say, 10^{-4} cm. radius down to 10^{-5} cm. radius, or less. Thus, the relation between the observed velocity due to this variation and the velocity due to Stokes' law becomes :

$$\frac{v \text{ obs.}}{v} = 1 + A\frac{L}{r}$$

Stokes' law is thus modified :

$$v = \frac{v \text{ obs.}}{1 + A\dfrac{L}{r}} = \frac{2}{9}\,\frac{r^2\, g\, a}{n}$$

When the particle radius $r =$ the mean free path in air (about 10^{-5} cm. under normal conditions) since A is of the order $0 \cdot 9$

$v = \dfrac{v \text{ obs.}}{1 \cdot 9}$ v obs. being the observed velocity.

Thus, with a particle radius of 10^{-5} cm., due to the effects of the discontinuity of the medium with respect to the particles, and the mobility effects of brownian movement, the velocity becomes almost doubled. With particles 10^{-6} cm. radius, velocity of fall is practically increased to ten times its value if

Stokes' law—without Cunningham's modification—were applicable to particles of that size. Above the particle size limit for Stokes' law, i.e. above radii of 10^{-2} cm., a terminal velocity of zero acceleration not being reached, the particles will obey Newton's gravitational law, and will fall like rain, which has a maximum velocity through air of about 8 metres a second, not transcended because it reaches a maximum diameter. So far as is known, i.e. as a result of Perrin's experiments, the stratified portions of the staubosphere obey Cunningham's law if such stratification has only been determined for particles less than 10^{-4} cm. radius, the artificial atmosphere of gamboge particles of Perrin of $2 \cdot 1 \times 10^{-5}$ cm. radius exhibiting the distribution of layers will therefore represent the manner in which particles obeying Cunningham's law settle (in an undisturbed and quiescent air atmosphere). Thus, if mean free path is considered doubled at 6 km. height, and molecular content is halved, the velocity of fall of particles of 10^{-6} cm. radius is about twenty times that which would obtain if Stokes' law were applicable, instead of ten times—as near ground level—and of particles of 10^{-7} cm. radius, 2×10^{2} times the velocity if Stokes' law could apply, instead of 1×10^{2} times the velocity. Thus A remaining almost constant, and Cunningham's law being applied generally, the higher a particle within the size ranges where applicable, i.e. less than 10^{-4} cm. radius, the greater will be its speed of settlement. This is due to the fact that as particle size becomes less than the mean free path of the molecules of the dispersion medium, particles will have a tendency to slip between the molecules of the medium. Thus, particles less than 10^{-4} cm. radius (the lower limit accepted for the operation of Stokes' law) will have an increased fall velocity with increasing height, appearing as a deceleration (i.e. reducing velocity) when falling. For, as such particles continue to fall through air becoming gradually denser, their mobility will become gradually less owing to the gradually decreasing mean free path of the molecules of the dispersion medium (air) and the nearer approach to unity of L for air of normal density and particles of radius about 10^{-5} cm. In effect, the larger particles actually obeying Stokes' law will always considerably exceed the velocity of particles obeying Cunningham's law. And in air of decreased density the difference in velocity between the two classes will be slightly reduced as density of medium decreases. This deceleration

of particles of less than 10^{-4} cm. radius, in air, is not merely a suspension of (as in Stokes' law cases), but a reversal of, the effect due to the gravitational law (6*a*). It is clear from these considerations that the staubosphere will contain at least three definite particle zones or divisions (sharp lines of division not being postulated).

These three divisions of the staubosphere will be: (1) The largest classification suffering acceleration of velocity with fall; (2) the medium-sized classification possessing no acceleration with fall; (3) the smallest classification suffering reducing velocity with fall.

The application of different laws determine these different classifications thus:

TABLE IV

Particle size limits.	*Mode of settlement.*	*Governing law of settlement.*
1. Greater than 10^{-2} cm. rad.	Accelerated	Newton's law
2. 10^{-2} cm. to 10^{-4} cm. rad.	Not accelerated	Stokes' law
3. Less then 10^{-4} cm. rad.	Decelerated	Cunningham's law

THE THREE PARTICLE SIZE ZONES OF THE STAUBOSPHERE.

Particles belonging to class (1) obeying the gravitational law, where, for such particles, the medium has maximum continuity, will overtake and pass through particles of classes (2) and (3). Particles of class (3) will, as a class, be longer suspended than either classes (1) or (2), both the latter moving through it at different speeds.

Particles of class (2) will, as a class, move through those of class (3), but be moved through by those of class (1). Particles of class (1) will draw further apart as they fall; those of class (2) will keep their distance as they fall; those of class (3) will draw closer together as they fall.

The great preliminary implication arising from the existence of these three classes in the staubosphere is that, whilst falling or settling (in an undisturbed and quiescent air atmosphere), though the respective members of any one class of similar dimensions (where impact would produce least mutual effect) are not very likely to meet, the members of the different classes will be continually meeting under impact (where impact, owing to size variation, will produce most mutual effect). This appears as a great fundamental basis of a natural system

directed to the attrition of particles of different sizes. As between classes (2) and (3) it is to be carefully noted that the maximum variation in velocity (implying more numerous impacts) obtains in the regions of most molecular content of the medium. The effects of the impact will, therefore, be more modified by the interposition of the medium; the medium will have more effect in controlling the direction of the particles; and impacts will, therefore, be less effective. It is to be noted that the smaller the dust particle, the higher it is carried by winds and convection currents (*cf.* Dust in Nature). This higher transportation of the finest particles which obey Cunningham's law will intensify the effects they experience of less rapid settling than the Stokes' law particles, and tend to restore them more nearly to their original altitude in the atmosphere than will be the case with the latter. Similarly, as between classes (1) and (2), the latter Stokes' law particles will be moved higher and more freely by these forces than the former Newton's law particles. These causes will result in the establishment of different amplitudes of movement for the three classes. The most horizontally mobile particles of class (3) will have the greatest horizontal amplitude of movement throughout the higher regions of the atmosphere. The particles of class (2) will have less of horizontal, and more of vertical movement, and those of class (1) will have greatest amplitude of vertical movement. Since, generally, the greater the height the stronger the wind pressure, the higher velocity of class (3) particles at greater heights will be offset by this increased wind pressure. Their increased mobility also will allow them to pass between medium molecules upwards as well as downwards, and this will assist appropriate wind movements in raising them. The higher they are, the higher they are, therefore, likely to remain for considerable periods. With regard to Stokes law particles which cannot so readily pass between medium molecules—less than a height where the medium mean free path is 10^{-4} cm.—and are, therefore, less mobile, there will be the one factor of wind pressure, convection, etc., tending to keep them up at higher levels; whilst with particles obeying the gravitational law, whilst wind pressure, etc., will tend to keep them up, there will be the gravitational force overcoming the lifting force.

The general tendency, therefore, taking into account the action of winds, convection currents and diffusion, may be

for the finest particles of the staubosphere to refrain from appreciable settling in the atmosphere, and for the largest to keep falling towards the earth. Diffusion may be regarded as to some extent operative because the finest division of particles is, in fact, tending to an approach to the threshold of dimensions when diffusion, as in gases, is commencing to apply, owing to the tendency of the particles to pass between the medium molecules, whilst the largest division of particles are still discrete solid units in a continuous gaseous medium obeying the gravitational law.

The view of Owens that the Aitken (28, 29) method does not distinguish between "dust" particles and other nuclei, and that of Boylan (385) that the method deals with hygroscopic nuclei only, leads up to the consideration whether in fact the various methods of counting the staubosphere particles are not each selective with regard to a certain dust zone—dust being regarded in the widest sense. Thus, whilst Aitken's apparatus may operate selectively with regard to hygroscopic nuclei, if the thermal precipitation and ultra-microscopic methods are comparable, they probably operate selectively with regard to particles greater than hygroscopic nuclei, but less than those selected (visibly) by the Owens jet dust counter. Allowing for some overlapping, this would imply that the total staubospheric population would be given by the sum of the counts of the three methods: (*a*) Aitken's; (*b*) ultra-microscopic; and (*c*) jet dust counter. The electrical precipitation method being regarded as more selective than the Aitken method within the same region.

The evidence for the selectiveness of the Owens jet dust counter of the larger particle content is (1) the relatively low count, and (2) the fact that, with fresh smokes, 30% or more passes to the pump unprecipitated, whilst after ageing (i.e. coagulating to larger particles), considerably less passes to the pump—Whytlaw-Gray and Patterson (205). Furthermore, the smallest smoke particles counted therewith are probably of the order of 0·5 u.

In the damping chamber of the jet dust counter, the particle content will be divisible as above shown into the three zones, subject, respectively, to (1) gravitational settling; (2) Stokes' law; and (3) Cunningham's law. When the pump is operated, the rarefaction caused in the damping chamber will operate differently on each zone of particles. On (1) gravitational

settling will be greatly assisted; on (2) not appreciably (the air density factor being taken as approximate or inappreciable in the formula); on (3) settling speed will be slightly increased owing to decrease of air density and increase of mean free path, and mobility in $A\,\frac{L}{r}$. The effect of this different action on the three zones, quite apart from the results of the adiabatic expansion, will be most effective selection of zone (1) and relatively less selection of zone (2) than of zone (3), though velocity of (2) will still be considerably greater than that of (3). The larger particle content will, therefore, be most effectively selected. On condensation it will, therefore, occur selectively on such larger particles, and these will be preponderatingly transferred to the strip record. Of the finest zone of particles, the finer they are, the less will they be selected, but most being transferred to the strip will be of dimensions less than lower microscopic visibility limit, and less than 10^{-4} cm. radius. This will occur when the damping chamber is held vertically with open end highest. If held horizontal, further complications will arise owing to the balance of forces established between the suction and gravitational complements; whilst if held vertical with open end lowest, there will be a greater tendency for modification of large particles recording themselves. With the thermal precipitation, the hygroscopic nuclei component is likely to be completely ignored. The smallest particles obeying Cunningham's law are likely to be selectively collected by this method, because, having greatest mobility and freedom to move between the medium molecules, they will readily move away from the direction of greatest molecular bombardment of the medium molecules, owing to the greater force exerted on them by that greatest bombardment. Near the hot plate, the higher temperature will cause greatest molecular bombardment, and the most mobile, i.e. smallest particles, will be forced selectively to the cold plate. They will be followed more slowly by other, i.e. Stokes' particles, but particles which do not show the effects of bombardment are not likely to reach the cold plate. This method is, therefore, probably likely to record particles from, say, 10^{-1} cm. radius downwards to about 10^{-5} cm. radius—the neighbourhood of lower microscopic visibility—and a large part of the largest particle component, probably chiefly

registered by the jet dust counter, is likely to be ignored. The ultra-microscope giving similar counts to the Aitken method, the latter may be regarded as including all finer particles as well as hygroscopic nuclei. Aitken's count, if Boylan's (385) suggestion be correct, that it ignores all but hygroscopic nuclei, would require supplementing by the ultra-microscopic count.

It would seem, therefore that the true valuation of the staubosphere content is likely to be given by the sum of the counts on any given sample of: (*a*) jet dust counter, (*b*) Aitken's method, and/or (*c*) the ultra-microscopic method, the jet dust counter being used vertically with open end highest. The total figure will probably be slightly less than the actual staubospheric content owing to some agglomeration—particularly with the jet dust counter—but this may be offset by a certain amount of overlapping of the different regions by the different methods. If thermal precipitation gives counts of the same order as the jet dust counter (528), counts of the same order as the ultra-microscope, Aitken's method counts agree closely with the ultra-microscope (205), then the jet dust counter must give similar counts to the Aitken method. The ultra-microscope method certainly gives much higher counts of the same air than the jet dust counter. Aitken's method—counting hygroscopic nuclei (385, 386)—and also giving higher than jet dust counter counts (213). Unless, therefore, it be concluded that different methods are counting different and supplementary staubospheric complements as above advanced—which happen to be similar in number—the only alternative conclusion is that a serious contradiction is involved.

If the sum of the three methods give the correct total content, then there arises the remarkable coincidence that whilst there are three zones of the staubosphere each governed by a different falling law, there are also three various dust contents assessable in number by different methods. The zones are delimited by particle size variations of, say, greater than 10^{-2} cm., 10^{-2} to 10^{-4} cm., and less than 10^{-4} cm. radius. The respective counting methods may be delimited by particle size variations of, say, greater than 10^{-2} cm., 10^{-2} to 10^{-5} cm., and less than 10^{-5} cm., supposing Boylan's contention correct (10^{-2} cm. being chosen as that above which gravitation particles may be selectively recorded in the jet dust counter if solely selected—which is unlikely). This coincidence is striking, and

there is a possibility of underlying reasons owing to possible relationship between different methods used and different laws establishing zones. But, *prima facie*, nothing but coincidence can be suggested.

The different laws of settlement or fall applying to the different particle zones refer ideally to spherical particles. Since, however, slight surface variations from spherical make very little difference to a particular mobility, the laws can be extended to apply to the actual particles of the staubosphere.

THE DISINTEGRATION OF DUSTS AND THE INTEGRATION OF SMOKES.

The combination of small ions and nuclei—E. von Schweidler (399), of large ions—Kennedy (400), rate of nuclei disappearance—Nolan and Enright (401), and of small ions—Rutherford (402), can be expressed by an equation of form:

$$V = V_0 + kt$$

and this can be applied to coagulation of smokes as such—Whytlaw-Gray and Patterson (205)—before coagulation ceasing, they become dusts, where V = particulate volume at time t, and V_0 and k are constants for any particular system. For the coagulation of the disperse units of suspensoids, Tuorila (403) showed that the expression also held, whilst Smoluchowski (15) showed that in suspensoids, if n = number of particles in unit volume, $4\ \pi\ dSn$ will be removed in unit time by a sphere of radius S to which all colliding particles adhere, D being the diffusion constant. Supposing D and S the same for each particle, if, as is actually the case, all particles act like one—S then: $2\ \pi\ DSn^2$ will be removed in unit time. The diffusion constant D according to Einstein (13) is given by:

$$D = \frac{RT}{N} \cdot B$$

where B = mobility, and R and T are the gas constant and the absolute temperature, respectively. Substituting Stokes' value for B viz.,

$$B = \frac{RT}{N} \quad \frac{1}{6\ \pi\ n\ r}$$

the equation $v = v_0 + kt$ finally becomes:

$$v - v_0 = \frac{2}{3} \frac{RTs}{nN} \cdot t$$

It was found that the coagulation equation of Smoluchowski (15) applies to homogeneous smoke systems as well as suspensoids—Whytlaw-Gray and Patterson (205), though Muller's coagulation equation (404) for suspensoids containing but *two* particle sizes, experimentally confirmed by Wiegner and Tuorila (405) does not apply owing to larger particle size range in heterogeneous smokes.

Whilst, however, this parallel of coagulation exists between smoke systems and suspensoids of solid disperse phase in liquid dispersion media, it does not seem possible that it can be extended to include all aerosols, for dust systems are definitely different from smoke systems in that the particles tend to disintegrate and become smaller, rather than coagulate and become larger. This definite distinction is involved in the different amplitudes and rates of movement of the various classes of the staubosphere, obeying respectively, the gravitation law, Stokes' law and Cunningham's law, and can also be reached by extrapolation of the known geological processes resulting in the formation of earth-formed natural dusts. Whilst, therefore, the colloidal division of aerosols contains systems which both (*a*) grow by coagulation, and (*b*) grow by disintegration or degradation; that of suspensoids grow only by (*a*) coagulation, and this applies also to the division of emulsoids. Growth, either larger or smaller, is a function of the life tendency of the particle size in any particular system. Whilst in aerosols this function may be either (1) increasing, as in smokes, or (2) decreasing, as in dusts, in suspensoids it is only (1) increasing. In foams belonging to the same class it is also increasing, whilst in those systems which have a solid dispersion medium, it is practically arrested. This function of life tendency of particle size is, therefore, seen to have widest scope in systems of gaseous dispersion medium; medium scope in systems of liquid dispersion medium; and minimum scope in systems of solid dispersion medium—Blacktin (406). The general quality of the three physical states which would seem to give rise to this variation in scope of function, is the mean free molecular path, largest in gaseous dispersion media; medium in liquid dispersion media; and smallest in solid dispersion media. This generalization is to some extent supported in a restricted sense by the Svedberg constant (16) which states that $mn = k$ where $m =$ mobility of particles under brownian movement; $n =$ viscosity of

dispersion medium; and k = a constant; for suspensoids, and Cunningham's law (8) indicating the variation in the velocity of particles as determined by Stokes' law (6) when particle radius and mean free path are becoming coincident in dimension, i.e. $A\,\frac{L}{r}$.

If the growth of a typical smoke system be considered, the particles gradually coagulate, the number of particles decreasing and their size increasing. On the other hand the growth of a dust system witnesses increasing particle number and decreasing size. Although these operations are strictly opposite as regards direction of particle-size growth, therefore exhibiting in aerosols a doubly-wide scope for this function as contrasted with suspensoids, emulsoids, eutectics, solid solutions, etc., the opposition is confined to direction of size growth, and does not seem to involve the application of different laws governing the two kinds of systems (viz. smokes and dusts) as may, at first, appear to be the case. For it has been shown by Whytlaw-Gray and Patterson (205) that the larger coagulated smoke units—from the study of their rate of settling—have a similar effective density to that of the original smoke particles. On the other hand, in dusts, the effective density will increase with particle size until, when the particles are sufficiently large, they have the recognized density of the parent mass. The reason for this important difference is that the coagulated "particles" of smoke systems are actually separate colloid systems formed inside the parent colloid system (or embryonic colloid systems) and consisting of gaseous disperse phase in solid dispersion medium—the growth of the disperse phase particles being practically arrested as explained in the general scheme—whilst throughout the whole range of dust particle sizes the particles remain discrete units, no matter how large or small. A coagulated smoke agglomerate may be and often is of so large departure from spherical form that its effective radius is difficult to compute. Since, however, its rate of fall is analogous to that of the younger, smaller particles in the expression:

$$r^2 = \frac{9}{2}\,\frac{n\,v}{a\,g}$$

v and a (i.e. velocity and density) remaining practically unchanged, and the other values being constant, the effective

radius is that of the initial particles. With large dust particles, however, which like relatively small ones are still generally discrete, the density a and the radius r are proportionately and actually increased.

Although, therefore, considering both smokes and dusts as regards growth, the scope of the life tendency of particle size is a maximum and opposite, the actual effect on the factors deciding the operation of the governing law is coincident, smoke particles behaving as though they had not coagulated to form visibly larger units, but remained small, and dust particles (like all smoke particles) obeying Stokes' law between, say, 10^{-2} and 10^{-4} cm. radius, and ceasing to do so when greater than 10^{-2} cm. radius. Whilst, therefore, in smokes the visible size increase due to coagulation effectively exhibits the maximum scope of life tendency of particle size, the agglomerates or grown " particles " are really not particles but pseudo-particles, being not discrete like dust particles of similar visible dimensions, but complete separate colloid systems.

The joint effect, therefore, of relatively large agglomerates behaving as small particles in the one case, and relatively large particles behaving as such (and different from small ones) in the other case, is due to the smoke system gradually changing with age from a two-phase to a three-phase system. Thus, on formation, a smoke system will have :

Dispersion Medium, A ; Disperse Phase, B ;

Almost immediately after formation, and continuingly and increasingly, a smoke system will have :

Dispersion Medium, A ; Disperse Phase (Embryo Colloid System of Dispersion Medium, B and Disperse Phase, A).

In its three-phase state the disperse phase of the parent system is, at the same time, the dispersion medium of the embryo system.

Particle-Size Determination and Particle Condition.

The efficacy of methods of particle size determination in any system generally depends upon the condition of the particles themselves more than any other factor. For whether size is determined from rate of sedimentation (Stokes' law), brownian movement and rate of diffusion (Einstein's law), intensity of scattered light (Tyndall effect), or oil-drop (Milli-

kan's) method, and whether the particle sizes being determined are those of suspensoid, smoke or dust systems, the particle density is the most important factor. Thus, whilst in dust systems the particles are discrete, possessing densities more or less in accordance with their size, as also in suspensoids, this will not apply in smoke systems where size has no straightforward connection with density owing to the colloidal, as disinct from the discrete, nature of the particles. On account of the phenomenal nature of smoke particles which are always, to some extent, agglomerated even before they can be first examined, their density has been regarded as that of a sphere of the same mass which falls at the same rate, which should approximate to the true density—Whytlaw-Gray and Patterson (205). On this value for density, particle-size determinations have been generally made by measuring the velocity of fall. Millikan's oil-drop method has also been used, assuming unit electrical charge values and using the calculated density.

A direct method of size determination is that of examining the sediment of particles on glass under a high-power microscope objective, in transmitted light through a calibrated eyepiece. For any particles which can be observed independently, and whose form can be seen, this method should be applicable and will, theoretically extend to the lower limit of microscopic visibility, viz. 0.2*u*—though particle size may be modified by pressure on the supporting glass. For similar sizes, methods which apply to dusts will also apply to smokes, but their application to dusts will be more simple owing to the discrete nature of the particles.

In using the sedimentation method the densities of disperse phase (particles) and dispersion medium (air or gas), d_a and d_b being respectively known, and the velocity v being determined, the particle radii r can be found from Stokes' equation:

$$v = \frac{2}{9} r^2 g \frac{d_a - d_b}{n}$$

by substitution, when n, the medium viscosity, is known. But, if the particle size is approximating to the mean free path of the medium molecule, i.e. in air at normal pressure and temperature, less than 10^{-4} cm. radius, the correction due to Cunningham (8) must be introduced into the Stokes' equation, when:

$$v\left(1+A\,\frac{L}{r}\right)=\frac{2}{9}\,r^2\,g\,\frac{(\,d_a-d_b\,)}{n}$$

L, being mean free path, and r particle radius, and A a constant of value approximately 0.9 for particles between, say, 10^{-4} cm., and 10^{-5} cm., and varying slightly for other radii.

In the case of the fall of dust particles or nuclei on which moisture has condensed to form drops, if air density is neglected compared with that of water, and viscosity of air at 15 degrees C. is $1{\cdot}81 \times 10^{-4}$, the equation for particles between 10^{-2} and 10^{-4} cm. radius becomes:

$$v = 120 \times 10^4 \times r^2 \text{ cm. per second,}$$

from which radii of drops are readily calculated, velocities being known.

The method due to the measurement of diffusion, and use of the Einstein diffusion constant is not very accurate, and requires many observations because r particle radius varies inversely as L where L is the displacement in time t in the equation:

$$D=\frac{1}{2}\cdot\frac{L^2}{t}$$

D being the diffusion coefficient, but the smaller the radius, L being the greater, is more observable. The diffusion is measured as brownian movement L, r the radius being obtained from the equation:

$$r=\frac{R\,T}{N}\cdot\frac{\theta}{3\,\pi\,n\,L^2}$$

where n = medium viscosity, R = gas constant, T = absolute temperature, and N = avogadro constant, found by equating Einstein's further value for D, viz.

$$D=\frac{R\,T}{N}\cdot\frac{1}{6\,\pi\,n\,r}$$

with the above value for D. The modification factor of Cunningham, viz. $A\,\frac{L}{r}$, must also be applied here where appropriate. The displacement D can be determined with the ultramicroscoscope, since Einstein and Smoluchowski (14) regard the length of the straight line joining initial and final position

of observed particle in a fixed time, as giving the appropriate value.

The determination of particle radius from the intensity of light scattered by the particles, depends on the application of the equality put forward by Rayleigh (25) in 1871, viz.:

$$I_S = A\ n\ r^6/y^4$$

where I_S = intensity of scattered light, y = wave-length of light, n = number of particles, and A is a constant.

When y and n are constant:

$$I_S \propto r^6$$

If, therefore, the intensity of the light be photographically measured, the particle radii are proportionate to the sixth root of the intensity for monochromatic light, and the fourth root for light in general. The constant A depends on the value of I; on the refractive indices of both disperse phase and dispersion medium, and the angle at which the beam is viewed, and the intensity is proportional to the concentration of the disperse phase for a given dispersion and light of given wave-length. By comparing intensities with the Capnometer, already described, in terms of amplified electric currents, the various particle radii will be likewise comparable.

Mie (407) showed that Rayleigh's law should be applicable to particles with a diameter less than 0·1 × wave-length of light. For particles of larger radii, however, the sixth power of r will gradually decrease to less than the second power, rising again to the second power, when particles large enough to act as true reflectors are considered.

The modification in the Millikan oil-drop method consists in observing the initial and final velocities of particles falling under the joint influence of gravitation and an electric field X. This field may reverse the particle direction, and cause it to rise or, partially or totally neutralize the gravitation effect. If the particle carries one electron of charge e, and v and v_1 are the initial and final velocities, respectively, of particle, mass m, then m will be determined from formula:

$$\frac{v}{v_1} = \frac{m\,g}{Xe - mg}$$

where g has the usual significance.

Experimental details of determinations of fall rate of particles may be obtained from Bär (408), and Ehrenhaft (409), and for smokes in particular Patterson and Whytlaw-Gray (205*a*).

If the speed of settlement of a particle in the atmosphere can be observed, then an approximation of its radius can be obtained, if it be supposed of unit density and the air density be neglected, from the resulting simpler form of Stokes' law (already applied to raindrops) :

$$v = 120 \times r^2 \times 10^4 \text{ cm. per second.}$$

This shows particles to settle through the air at velocities varying directly with radius squared, and in case of a particle, say, 2u diameter, the velocity would be 0·012 cm. per second.

CHAPTER VIII

DUST IN GEOLOGY

DUST IN GEOLOGY.

THE geological study of dusts is, of course, an intrinsic section of that science, and also the important birth story of all save cosmic, industrial and everyday dusts. It is the study of the inception and creation in nature since the earth's formation of all earth-formed circulating dusts. It is the story of an age-long progression, of an unceasing change in the multifarious forms of innumerable parent objects towards the generalized form level (whose distinctions under the microscope may equal those of the parents) of dust particles.

Primeval land buried beneath sand throughout almost all geological time, has shown on removal of the resulting sandstone, that pebbles were shaped by the primeval wind-blown sand. The sand grains are of the same size as those now passing ; the wind direction is still west as in archæozoic times. In the words of J. W. Gregory (469) : " As these old sandstones decay their grains fall apart and are subject to the action of winds of the same force and direction as those which carried them to their present positions in primeval times ; and the sand-grains resume their interrupted journey north-eastwards after a delay of perhaps hundreds of millions of years. The imprints made by drops of rain upon beds of soft clay on the sea-shore or beside lakes, show that the raindrops of the earliest ages were of about the same size as they are now and fell with the same force as in modern storms. The physical evidence of rocks made by the accumulation of sediment under the influence of wind and rain, shows that the oldest known climatic forces were of the same power as those which act on the surface of the earth to-day."

It has been previously advanced how the necessity for rain formation and vegetable growth ; and the possible introduction of organic life to the earth, probably depended on the existence

of dust from the earth's foundation. Whilst the earth's chief surface features are due to its internal changes, denudation—of which dust formation and removal forms but a part—having, as it were a finishing effect, though an immense one, such internal changes have themselves made dust formation possible. For, in the earth's formation from meteorites, their metals have gravitated to the core and their minerals to the surface (*cf.* analogy of molten metals).

The primary rocks thus formed had first to be broken up by temperature changes due to the sun before even plant and lower animal life could exist. And as the temperature at first on the earth was probably constant, day and night and all the year round, this would be a slow process. Dust was a concomitant of this original disintegration and then partook of the succeeding sedimentation and denudation. Plants and animals grew and, decaying to dust, fertilized the earth for the use of man, whose activities are almost completely carried out on the sedimentary areas largely formed by the action of dust in laying-down secondary rocks. The supply of primary rocks for dust degradation and denudation has been kept up by uplifting due to further rearrangements in the earth's barysphere. Scandinavia is an example of land which, owing to being thus raised as fast as denuded, has never been submerged under sea, and other so-called coigns—which must consequently be regarded as chief dust-forming regions—are Labrador, parts of India and tropical Africa, Western Australia and Brazilian Highlands.

THE GEOLOGICAL PRODUCTION OF DUST.

The operation of geological dust formation—weathering—produces fragments of differing constitution from the parent substance, when chemical ; mere disintegration thereof, when mechanical. The intensity of weathering depending on the degree of temperature variation, it will be particularly intensive in hot deserts (where nights are cold). In some rocks, e.g. granites, there will be weathering differentiation between components of differing specific heats, and the crystals of crystalline substances may be split. Weathered material collecting at cliff feet may, on being wet, produce landslides. Apart from the huge amount of new dust implied, vast dust clouds must be raised by such falls as, e.g. one in the Himalayas moving 8×10^8 tons of material in three days. In November,

1932, 15×10^6 tons of cliff crashed into the sea near the South Foreland, England. Observers at some little distance were blinded by chalk dust clouds from the landslide. Chemical weathering includes oxidation, carbonation, and hydration, and, like rocks, soils and smaller individual masses suffer weathering which will be the more rapid the softer the original material. To quote A. Geikie (238), "the fine microscopic dust so abundant in the air is no doubt due for the most part to the action of wind in lifting up the finer particles of disintegrated rock on the surface of the land. Volcanic explosions sometimes supply prodigious quantities of fine dust. There is also probably some addition to the solid particles in the atmosphere from the explosion and dissipation of meteorites on entering our atmosphere. To the wide diffusion of minute particles in the air great importance is now assigned in the condensation of vapour. The radiant heat in the atmosphere is absorbed by water vapour together with carbon dioxide and suspended dust particles. Chloride of sodium is particularly abundant in air bordering the sea. The organic substances present in the air are sometimes living germs such as particularly often lead to the propagation of disease, and sometimes mere fine particles of dust derived from the bodies of living or dead organisms."

The agents of such operations are (1) the atmosphere; (2) the hydrosphere; (3) the pyrosphere; (4) the biosphere; and (5) lithosphere movements. These agents will obviously operate either chemically or mechanically dependent on the chemical nature of the parent material.

(1) *The Atmosphere in Relation to Dust Formation.*—The chief operation of the atmosphere will be mechanical. Moving air—which is, of course, the rule—and winds transport great quantities of weathered material, much of which has been previously transported. In exposed situations transportation keeps pace with weathering. Stony deserts are examples of this action, where the remaining coarser units are often polished by the abrasive action of wind-swept finer units. Thus is the Swabian Alps plateau kept bare of soil, and thus, no doubt, was the considerable amount of wind-worn silica glass covering 20 km. × 20 km. between sand dunes in the Libyan Desert found by P. A. Clayton of Survey of Egypt, about 480 miles south-west of Cairo, a lump of which has been recently deposited in the British Museum. The abrading units will thus either

become smaller or form smaller units from themselves, and also from the abraded units, furthering the continuous dust degradation process. All transportation will also produce degradation of both abrading and abraded units, for weathered, wind-carried products are travelling abrasive systems.

The Libyan Desert shows numerous examples of limestones deeply grooved by the wind-dust abrading agent. Their formation is probably as old as history, and their particulated lost matter added to the staubosphere may, driven by the prevailing winds, have often aggressively revisited the parent rock. The existence of such grooved rocks covered by others, as in Michigan, is read as indicating periods of great wind activity between the deposition eras of the respective rock formations. The severe action of these travelling abrasive systems in constantly reinforcing the staubosphere is indicated by the necessity to (*a*) protect telegraph poles from abrasion by rock piles in the San Bernardino Pass; (*b*) replace the semi-worn telegraph wires in some deserts after a few years; (*c*) the formation in deserts and other exposed places of sharp-edged pebbles with two (einkanter) or three (dreikanter) faces. Soft rocks often transfer their complete material to the dust of the staubosphere under this mighty influence and harder ones add a dust population resulting in smoothed ground surfaces for themselves. Infra-red photographs taken from the Imperial Airways England-Singapore line, disclose on the fringe of the Baluchistan desert weird-shaped rocks due to the disintegration of torrential rains and "to the cutting of sharp facets by the sand-laden winds." Also declivities of sheer sides caused by fragment separation under violent weathering. (*Times*, March 8th, 1934.) Where the abrading units are hard, the disintegrating action will result in their gradually becoming spherical. As previously pointed out, unless this has occurred with combustion or vaporization, new fine particles have been formed in the process. The final effect of the crevicing action is sometimes to produce separate rock pillars which are, subsequently, still more open to abrasive action, and such pillars—whose formation is the evidence of extensive addition to the staubosphere—are found in the Libyan Desert, Colorado and Saxony. W. Flinders Petrie (239) records that in parts of the Nile delta about 4 ins. of soil per century has been wind removed for twenty-six centuries to a total depth of 8 ft. of

soil. The travelling abrading system has left its mark on walls and buildings, and Egyptian monuments are well polished by the abrading Libyan Desert sand. J. Walther (240) and M. Choisy (241) also record rock polishing by Saharan-blown sand. The coal discovered in the Sahara—N. Menchikoff (242)—may one day add this basic industrial dust to the age-old desert sands. In Wyoming, even chalcedony has been abraded into furrows and acquired a glaze—" desert polish "—whilst blocks of sandstone or limestone have their bases worn away, topple over, with repetition of the process, due to the ever-travelling particle abrasive—A. Geikie (138). If, as is the case, dust is formed from metallic bismuth, merely by polishing with the hand surface, some mineral substances are likely to be very easily eroded, and even the Henbury (central Australian) meteorites of iron have suffered erosion and weathering.

The intensity of this abrading action may be realized by comparison with that occurring on suspended particles in liquids, e.g. rivers. Air-abraded particles become the more spherical, and finer particles suffer abrasion in air than in liquids. The disintegrating action in the atmosphere is, therefore, more intense than that—more easily realized and envisaged—between submerged particles. So much so that the difference is employed as a tentative means of distinguishing between air and water-worn sand grains.

The other agents, though much less generally effective than the atmosphere, are of considerable importance in the maintenance of the staubosphere.

(2) *The Hydrosphere in Relation to Dust Formation.*—Action of the hydrosphere comprised in rain, sea margins and rivers will affect the staubosphere both by augmentation and depletion. Thus, whilst rain is constantly removing particles by virtue of, probably, the majority of drops using particles as nuclei, and by solution or suspension of particles in falling, or streaming of settled particles to rivers and seas, the falling of rain on rock surfaces will, generally, cause sudden temperature changes (the specific heat of water being high) which greatly assist disintegration, feeding the constant, travelling, abrasive systems with fresh supplies. On all coasts the pounding of the waves is ceaselessly disintegrating rock materials and sands, and though carrying disintegrated material into the sea, is still adding to that available for dispersion by winds into the staubosphere. Rivers, chiefly engaged in removing

fine particles to their own, or the sea beds, also form banks which are often available for the dispersing action of the winds. On the Scotch coast, wave forces varying from about 600 to over 6,000 lb. per square foot from summer to winter, and under various conditions, have been measured, with a maximum of 6,083 lb. per square foot in March, 1845, and French, Italian, and North African records afford values from 600 to 3,000 lb. per square foot, according to Grabau (112).

(3) *The Pyrosphere in Relation to Dust Formation.*—Volcanoes —representing the pyrosphere—contribute a vast dust population, and considerably affect atmosphere and climate, as shown by H. H. Kimball (61) and Abbot and Fowle (62). The particles—not the ash of combustion only, but finely-dispersed, solidified lava—are mostly so fine as easily to make their way into closed rooms, and, in eruptions, boxes, watches or other close-fitting joints cannot exclude the dust. Varying in composition with the lava, it microscopically exhibits numerous microlites—crystals with volcanic glass adhering. Such dust is minutely cellular and contains semi-circular or elliptic units, evidently pore walls of vapour-enclosing function in the molten rock—A. Geikie (138). Such dust, certainly fine enough to settle under Stokes' law (6) if discrete, will probably, on account of its colloidal (cellular) nature, actually have an effective settling rate attributable to much smaller discrete particles—Blacktin (243). Obeying rather Cunningham's law it will, therefore, largely appertain to the finest particle zone which, probably never settling, will have maximum horizontal mobility. This conclusion is important, indicating the addition of a large proportion of volcanic dust output to the permanent non-settling staubosphere. The gradation of settling with size and increasing distance from the eruption was noticed by Matteuci with respect to magnetite ejected by Vesuvius. When there is little lava overflow, as in some of the worst eruptions, there is often huge incandescent dust formation due to lava dissemination by accumulated gases, and also mud from the crater may be also dispersed to eventually form more dust. In the Mont Peléean eruption, Martinique, 1902, when 30,000 people in St. Pierre were obliterated in a few minutes, all lava was emitted as dust, and there was an avalanche of incandescent sand. The red-hot dust, mixed with gas (a colloid of solid or semi-solid disperse phase) rushed down the volcano side—flowing almost like a liquid—into the sea. All

such fine dust—when not so engulfed—will probably soon be dispersed in the staubosphere. Whymper (244) found dust 65 miles from Cotopaxi of fineness from 2,000 to 25,000 particles per grain. Supposing them spherical, and their density unity those of smallest radius—about 10^{-2} cm.—would represent the coarser component of the dispersed dust, as that of even one micron radius would travel over 8,000 miles in a wind of 10 miles per hour to settle a depth of 300 ft. (*cf.* previous sections).

Similarly, dust from Vesuvius in 1882, observed at Ascoli and Casano, respectively 56 and 105 Italian miles away, would be relatively coarse, and in fact, by the time the finer fractions settle, their base will be so distant as to give no immediate clue of their origin. But the particle size dust zone to which volcanic dusts belong would be likely to be smaller than their apparent size suggested if they were first formed as smokes, and then coagulated to agglomerates. The fact that they are shown to be due largely to lava dispersion, rather than combustion, confirms the facts of their relatively quick settling, in part, to show that in reality they are not first smokes, but are dusts from their first formation. In fact, size measurements of relatively large particles settled near Krakatoa in 1883 gave an average of 12 micron diameter, with some down to 1·2 micron diameter—J. S. Owens (245)—and the average size of particles emitted was 4 micron. Many such particles were angular with pitted surfaces, suggesting fragments of thin-walled bubbles.

Evidence of the immense dust addition to the staubosphere by volcanoes is supplied: (1) by the daily records of Dr. Wolf at Guayaquil, 150 miles from Cotopaxi from June 26th to July 1st, 1877, of deposits varying from 315 to 209 kgm. per square km.; (2) Cotopaxi eruption of July, 1880, when Whymper estimated a dust ejection of over 2×10^6 tons, or $1{\cdot}5 \times 10^5$ cubic feet of lava; (3) Coseguina (Nicaragua) 1835 eruption, when ground to a distance of 25 miles was covered 10 ft. deep, followed by a dust rain over an area of $1{\cdot}5 \times 10^6$ square miles; (4) Sumbawa eruption—1815—with dust fall over an area of 10^6 square miles, amounting to $50 \times \text{mile}^3$ of material = mass of Vesuvius $\times$ 185; (5) Sakurajima (Japan) eruption, when it was possible to walk 23 miles on floating debris in the sea; (6) Skaptar—Jökull—1783 eruption, when Iceland air was dust-laden for succeeding months, and 600 miles away dust fell in Caithness, destroying crops; (7) Icelandic volcano dust

has several times had to be shovelled from vessel decks between Orkney and Shetland Isles. Dust is also often formed by millions of stones alternately ascending and descending in the dark column over active craters, the dust column rising many miles into the atmosphere, and then dispersing horizontally. The dust from Krakatoa rose 17 miles, producing darkness for 150 miles around, whilst Cotopaxi—1877—at Quito, 33 miles distant, made the hand held before the eyes invisible. The island of Krakatoa (East Indies) was, in 1883, first practically disseminated, and over one cubic mile of dust was belched into the air. The explosion wave carried the dust three and a quarter times round the earth, i.e. 26,000 miles; the beautiful sunsets for succeeding months showed dust to be still circulating; and huge amounts of dust were three days later deposited on vessel decks 1,600 miles distant, whilst deep channels became unnavigable owing to being dust filled. The dust formed a world-wide layer 5 to 15 miles high, and a halo (Bishop's ring) round the sun of 15 degrees radius, due to diffraction. Assuming the particles causing this diffraction phenomenon as spherical, Perner calculated their diameter as 1·85 micron. In still air, assuming their fall obeyed Stokes' law (though, if cellular this, as explained might not be the case), they would require almost 4·5 years to settle from 17 miles height. In connection with Krakatoa, the theory of vulcanism, i.e. the production of ice ages by volcanic dust, must be referred to. Thus Arctowski (413) and Kimball showed that changes in solar radiation were produced, whilst W. J. Humphreys (414) has studied the general volcanic dust effect on radiation, showing that inward solar radiation would be prevented thereby, more than outward terrestrial radiation in ratio 30 : 1, solar radiation of, say, less than 0·5 micron being reflected by particles of, say, 2 micron diameter, and terrestrial radiation of, say, 12 micron wavelength being scattered. It should, however, be borne in mind that much volcanic dust is probably less than 2 micron diameter.

Forty-four years later (about six years ago) Krakatoa seems to have again become active by erupting from the sea-bed, casting up vast lava columns 3,000 ft. high, and successively producing Anak (Malayan = child) formations on four occasions, the fourth appearing above the sea August 11th, 1930, growing into a big island with a black sand beach. Many plant seeds had already germinated, including 41 coconut

plants, but after a few months all was again covered by further eruption—W. D. Van Leeuwen (246). Ash continued to fall for several days from the Mt. Peleean eruption, which first destroyed Martinique and 30,000 people, and scientists found fine ash still afloat a week later, whilst the whole of the West Indies was covered with white ash 10 weeks later from another explosion (110).

The earth-formed component of the staubosphere is, therefore, seen to penetrate far into the stratosphere.

W. C. Smith and G. Rayner (534) report the finding of slabs of clay-like rock, of very finely divided clay substance, more abundant colourless volcanic flake glass (from 0·15 mm. down), and feldspar grains (from 0·06 mm. down), and some green grains like glauconite. The glass and feldspar being similar to Andéean eruption glass (that collected in Buenos Aires in 1932 ranging from 0·2 mm. down), they suppose it formed from volcanic dust transported from Andes to Patagonian coast, where found.

(5) *The Lithosphere in Relation to Dust Formation.*—Dust is created in the lithosphere by the grinding of rocks against each other in earthquakes. Such dust is often flour-fine, and falls into the fissures caused by the earthquake. Huge amounts of surface dust are also produced by the destruction of surface objects—artificial or natural—as in the case of the extensive earthquake in India in January, 1934, which, in addition to the new phenomenon of voiding sand covering 2,000 square miles, often 3 ft. deep, and creating permanent desert from agricultural land, has altered land levels so that future river courses are still unknown before the next monsoons.

The action of glaciers is operative in forming fine dusts. Grinding its way over rocks, a glacier attaches the broken rock to its under surface. This it uses as a triturating agent, itself often ground to powder in removing further rock material. Much very fine dust is so formed, which, when not carried away in glacial streams—turbidifying them freely—will be raised, along with powdered snow and ice spicules, by circulating winds. Glacier ice will also itself be finely ground, retaining particle form above the snow-line; whilst the cooling effect of ice on sun-heated rock will produce rapid weathering. On glaciers dust wells are also formed by small particles melting and sinking into the ice.

(6) *The Biosphere in Relation to Dust Formation.*—Biosphere-

produced dusts are chiefly due to bacteria, plant growth, plant destruction, surface animal movement, and burrowing animals.

Some bacteria attack and disintegrate rocks, and in addition to rock destruction in fissures by tree and plant roots, their decay forms carbon dioxide and humic acid—which dissolve rocks. Organic acids from some animals will also have solvent action, and whilst termites and worms loosen surfaces and prepare them for wind raising, ants and moles loosen the under surface, admit air and assist pulverization. The author has watched burrowing in active progress in the Syrian Desert, and their disintegrating work may be further instanced by work in the Florida mountains and Idaho, where the most trustworthy clue to deeply-buried minerals were the particles of such brought up by ants. The edible seeds which ants cultivate is another aspect of their dust formation.

The greatest dust-producing agent, however, is probably the large herds of cattle in some vast open regions. In dry weather thousands are driven in to the remaining water holes. Their constant hoof pounding disintegrates to fine dust, over vast areas, the dry surface soil or rock, and huge amounts of this fine dust are raised by their constant passing and carried away by the winds. It will, of course, contain dust from their excreta, the wear and tear of hooves, and many bacteria. A herd of a thousand cattle of average weight one ton and hoof area frequency, say, 1 square foot per second, will exert a disintegrating pressure of $2 \cdot 24 \times 10^6$ lb. per second. Or, in a journey of, say, 10 minutes to a water hole, $1 \cdot 34 \times 10^9$ lb., exclusive of the muscular energy applied in the impacts. Such large dust formations are very prevalent in the Kalahari Desert, and the constant wearing down of the surface year after year produced ridges—for the cattle often file to the water—creating channels down which rainflow replenishes their drinking supplies. The soil erosion in Africa, causing a serious reduction in productivity, is partially caused by these hoof-formed water channels, according to A. M. Campion (247). Man-engineered cattle treks will also add considerable dusts to the staubosphere. Thus, in January, 1934, 3,000 reindeer are about to arrive in the Mackenzie River delta reserve, where they will solve a food problem for the Eskimo. Their dust production will, probably, be widely different from that in the hot deserts.

GEOLOGICAL DUST PARTICLE SIZE.

A practical size limit defining when solid material becomes dust would be that at which wind ceases to raise it. Pebbles of 8 mm. diameter or more may be carried by a strong wind, according to Grabau (112), and a descent of hazel-nut-sized white quartz pebbles fell at Trélex, Vaud, in 1907, having travelled over 62 miles (Rollier). In a more restricted sense, the upper size limit of particles which may be classed as dust is arbitrary, and P. Drinker (196) suggests a figure of 150 micron diameter. But in this section 8 mm. may be regarded as an arbitrary upper size limit. Such would, of course, be carried unappreciable distances as contrasted with very fine volcanic dust carried, say, thrice round the globe, before settling. In between these extremes, winds transport particles of all sizes and chemical natures. The heavier the particle (determined by size and density), the sooner will it be released in a given wind. This leads to wind sorting of size fraction and material fractions, given sizes and materials collecting in given localities. But the localities will vary with wind pressure variation, though keeping their own relative distance relationship approximately. In Michigan and Ohio, old sand deposits, wind-worn to spheres, similar sized and of same material, are found, due to ancient wind selection—Grabau (112). In addition to selection by carrying and settling, the wind selects by moving particles along the ground, in similar manner. The constant attrition due to both methods producing smaller original particles, and numerous small new ones, cannot be over-emphasized. Whilst glaciers and icebergs transport, they will not appreciably sort, dust.

Subject to wind strength and particle size and weight, distance carried will depend on the initial position of the dust, and whether wind energy is dissipated in lifting, previous to dispersing. Volcanic dust is independently lifted. All circulating dust, cosmic or earth formed, greater or less than 10^{-4} cm. radius, is in situ awaiting wind operation. All deposited dusts, e.g. from deserts, must be wind or air current (convection) raised as a preliminary. Extent of dust transportation, with constantly attendant attrition between particles implied by size sorting, may be gathered from: (1) The coarser dust from volcanoes is sometimes found several inches deep, 1,000 miles (Krakatoa); 1,000 miles (Tomboro); 750 (Cosequina); Atlantic-width (Mont Pelée) away. Vesuvius dust has fallen

in Austria, France and Greece, and Krakatoan dust in Holland—Grabau (112). (2) Desert dust (Sahara) carried to England and 2,000 miles to North Germany; (Australian deserts) to New Zealand, 1,500 miles; (Gobi Desert) to Japan, 1,000 miles. These long-transported dusts will be chiefly those greater than 10^{-4} cm. radius, obeying Stokes' law (6) which, of themselves, have chiefly vertical mobility. The still finer components will be obviously carried much further, and held in the atmosphere indefinitely—the permanent staubospheric complement.

TYPICAL DUST-MOVING SYSTEMS.

The immense importance of storm dust falls may be culled from (1) the Canary Island fall of $6{\cdot}5 \times 10^6$ tons in 1863, (2) the European and North African falls of respectively 2×10^6 tons and $1{\cdot}65 \times 10^6$ tons over sea and land areas respectively $1{\cdot}7 \times 10^5$ and $3{\cdot}0 \times 10^5$ square miles—some having travelled 2,500 miles—in March, 1901.

Of wind-carried sands, those not entering the sea characteristically form dunes on many coasts and over huge desert areas. The three dune types are all blown-sand-dust-formed. Their general characteristic is the shifting turmoil of the particles—always rubbing on and rolling over each other under ordinary winds, often lifted and lashed into violent storms and changed dune shape by violent winds. A continuous story of decreasing particle size and particle formation! Valleys, villages, churches, vineyards, forests are overrun by advancing dunes, which, travelling from 15 ft. to 105 ft. per year (an average figure on the French south-west coast is 81 ft. per year) progress by the continual wind rolling of grains up their windward sides, over their summits, and down the leeward sides. Some in the Sahara are known to have thus travelled 100 miles.

These vast dust deposits *travel by attrition.*

Save where angular grains are added from new weathering, the grains become smooth and round with ceaseless rubbing, obviously ceaselessly diminishing themselves and also forming smaller particles. The French coastal dunes—one of the largest representatives of that type—may reach a height of almost 300 ft., covering territory 150 miles long and 2½ to 6 miles wide. Asia, Africa, and Australia are the chief continents of inland dunes and deserts.

The vast extent of this constant deposited-dust degradation

can be gathered from: (1) Saharan content, $1 \cdot 8 \times 10^5$ square miles; (2) Arabian dune area, $1 \cdot 5 \times 10^4$ square miles (one-third total); (3) Australia—interior desert has many parts covered with drifting sands; (4) Nebraska, one-fourth total area, viz. about $1 \cdot 8 \times 10^4$ square miles; (5) California and Arizona containing many deserts.

Some dunes are buried and overgrown, e.g. the Hungarian Plain, and many deserts bear sands disintegrated from older sandstones, e.g. the Libyan Desert. The southern Arabian desert of Roba-el-Khali—12,000 square miles—is completely covered by wind-blown sands, and has no oases. The northern Nefud Desert is of red sands. The Gobi Desert—Shamo, Sea of Sand—is of Saharan dimensions, or much larger, if its north Tibetan branches are included. Asia has also the Syrian, Khiva Rajputana, Baluchistan, Seistan and Persian salt deserts, and Africa, the Kalahari—600 miles long—though this last contains much vegetation, the popular gladioli, for example, being indigenous to its bordering regions.

Large amounts of dust are also formed by dune engulfed objects, e.g. tree tops are visible above many dunes.

There are regions of size selection in dunes corresponding to different wind pressures, and study of cross-sections of dunes, along with particle size, shape, and material, may indicate varying wind movements at greatly separated periods. The particle size selection on windward dune surface causes a rippling effect—really a formation of a secondary dune system on the parent dune.

The huge dust movement nearer the earth's surface from deserts is typified by the world's vast loess deposits. The whole agricultural life of China for thousands of years, without artificial fertilization, has been carried out on the loess borne south-eastwards from the Gobi Desert, deposited through the ages—and still steadily augmented—to depths of often 1,000 or more feet, but more generally 200 to 500 feet. The deposited dust consists of very fine angular quartz grains, hydrated alum, silicates, mica, felspar, hornblende, etc., of sizes similar to those of clay particles, viz. less than 5 micron diameter. The structure of the loess deposit is such that road-making and weathering have cut vertical-walled canyons—sometimes overhanging—therein, several hundreds of feet deep. In places dwellings have been carved out in the loess walls by natives. The particle size seems to suggest considerable

disintegration in transit, for sandstone, and presumably sand particles, have a *lower* size limit of about 5 micron.

ENERGY AND PERSISTENCE OF MOVING-DUST SYSTEMS.

If the Chinese loess area be taken as of the order of 3.6×10^5 square miles, and its average depth 200 ft., the volume is 5.6×10^{19} c.c. Assuming average particle radius of 10 micron (and quartz density 2.5), the number of particles in the deposit is 1.4×10^{28}, requiring 2×10^{-3} erg to move each particle at 14 miles per hour. A wind of 14 miles per hour (light breeze), exerting a pressure of 1 lb. per square foot, of cross-section 1,200 miles $\times$ 100 ft. deep (loess deposits being, say, 1,200 miles long) would exert 9.15×10^{13} erg, which would move 4.5×10^{16} particles per second. The loess deposit particle number being, say, 1.4×10^{28}, about 10,000 years would be required to move from the Gobi Desert all the Chinese loess deposit, assuming a steady wind front of 1,200 miles and a dust cloud 100 ft. deep, over that period of time. Since wind would, of course, be really intermittent, and much energy be expended against gravity, originally lifting and re-lifting many times, particles settled upon the journey of, say, 300 miles, the period mentioned could only be a minimum. The travelling dust population would also widely and constantly vary in number per c.c. But these figures serve to illustrate the immensity, longevity, and tremendous significance of the dust transportation, and of natural aerosols necessary for the formation of the fertile and life-supporting mongolian loess.

This tremendous dust movement, filling a plain and burying mountains in one region, has helped in the general level-lowering of the initiating desert, continuously proceeding under the dust-forming conspiracy of erosion and drought. Evidences of its modern occurrence are not wanting, for Y. Wada noticed on March 4th, 1915, a "sand-mist" dust from interior China, which was moistened by accumulated water, deposited in a quarter-inch dust-layer at Etchu Province, Japan; whilst R. C. Andrews reports tremendous erosive effect of wind and water on western Chinese and Manchurian soils, and the huge dust storms (110).

In the Colorado plateau over thousands of square miles, material to a depth of thousands of feet has been abraded and removed.

Nor is the remarkable age-long dust action confined to the

raising and lowering of vegetation-free surfaces, for dust filtered from the winds by leaves and plants gradually percolates—even on grass-covered lands—raising the herbage and ground level above it. It will simultaneously alter the chemical nature and agricultural value of the subsoil.

On such sites as Babylon and Nineveh, where the often-dust-laden air gives rise to snow-like drifts, desolated cities have been buried through the ages, whilst in Central Asia the windless air is often thick with fine dust, in Khotan, sometimes necessitating artificial light at midday—A. Geikie (138).

Ancient cities have been buried in the Gobi Desert, and dust deposits are now being formed in some coral islands, e.g. Bermuda.

The black soil of Russia, intensely fertile, is another huge dust deposit, blackened by decayed vegetable and organic matter intermixed. It has a depth of, perhaps, 25 ft.

Loess in some regions is formed from glacier-created dusts which, becoming dessicated in inter-glacial epochs, is wind-dispersed into selected localities. Such loess occurs in the United States of America.

Much of the dust population of earth-surface winds is, in suitable conditions, filtered from such winds by obstacles such as trees, shrubs, and other vegetation, and in traversing rainy districts. The filtering vegetation gradually accomplishes its own dust interment, and is succeeded by fresh vegetation at a higher level. Where large tracts carry such vegetation, the result will be a gradual ground level heightening of the neighbourhood by dust. That not brought down by rain may largely be carried away, and, in any case, its form and nature will be changed.

THE SCOPE AND SIGNIFICANCE OF DESERT DUST MOVEMENT.

For deposited dust to be raised to an equivalent circulating height to volcanic dust, in general, work must first be done on it by wind. Such winds may be steady or violently spasmodic, with all intermediate stages. Steady winds will produce vast dust-raising effects such as the Harmattan haze. Violently spasmodic winds will produce cyclonic sandstorms and dust-storms. Owing to the almost-solid dust loads which are raised in such storms, added to the steadier effects, desert air is very often hardly ever free from fine dusts. This constant vertical dust motion is added to the slower, steadier, horizontal

motion of the particles of dunes in deserts, and is largely responsible—along with aridity—for absence of vegetation.

Naturally, in these circumstances, landmarks and the general contours are also constantly varying. These vast, raised-dust populations will contain earth-formed and cosmic, organic and inorganic, lifeless and living (though containing little bacteria) dust, and particles of all sizes.

According to their sizes, the particles will settle either (*a*) under gravity; (*b*) Stokes' law (6); or (*c*) Cunningham's law (8); as previously set forth. Whilst the (*b*) fraction will take long periods to settle, the (*c*) fraction constantly supplied and augmented by these movements themselves and by the never-ceasing dune travel attrition will practically never settle.

The constant dust-raising in the world's vast desert and dune regions is, therefore, a huge steady reservoir of supply of horizontal mobility particles which will continuously circulate through the higher atmosphere, feeding the world-wind systems in the way shown (*cf.* Dust in Nature) and supplying vast necessary nuclei population for the heavy rainfall areas.

The precipitation by rain, and the re-dispersal from deserts, will be a ceaseless cycle. Since the nuclei falling in rain are not returned to the dry desert regions—whose absence creates their function—this is really a vast, natural excavation work, no less than the accumulating of loess.

The formation and removal of dust in nature is, therefore, an immense, continuous sculpturing movement, a bouleversement of the earth's upper crust, an ocean-filling, land-levelling operation, conferring on dust an intrinsic importance second to none amongst the earth's intense and fundamental processes. Since softer rocks will be more quickly weathered and disintegrated than harder ones, the cumulative effect will be a tendency to more rapid disintegration to the finest particles than if harder rock particles were chiefly requiring to be broken down.

A. Dauvillier (541) comparing strange sounds from Greenland inland ice and the well-known "desert song" of sands, suggests close analogy "between the fields of powdery dry snow of the inland ice, and the fields of sand of the Arabian desert."

Miniature air-volcanoes in sea-shore sands, believed caused by water-trapping of air-pockets, have been studied by J. H. Orton (542).

CHAPTER IX

DUST IN BOTANY

ALL botanic dust, as such, will consist of pollens, spores or seeds of plants or trees. The dust derived from flora, e.g. that ground from trees by sand grains when dunes submerge forests, or from decaying leaves, or from barks of standing trees or plants bombarded by the wind-driven staubosphere, will be classed with the general staubospheric constituent.

NATURE OF BOTANIC DUSTS.

The innumerable units of the staubosphere will be either (1) lifeless (organic or inorganic) or (2) living—or able to become so. The more normal dusts will belong to (1) lifeless, which will be continually augmented from (2) living. The components of (2) will be (*a*) bacteria, moulds, fermenting organisms, etc., actually living, and (*b*) spores and seeds not yet germinated. Botanical dusts, therefore, are all those comprised under 2(*b*). They are exceedingly numerous and widespread, and are an almost invariable accompaniment of the other staubospheric components. Spores were discovered in New York air by E. E. Free (203) ; they have been discovered embedded in rock and sandstone formation—indicating their ancient staubospheric presence—and have been classified as to their occurrence in nine of the principal coal beds of Eastern U.S.A. by G. C. Sprunk and R. Thiessen (227). Moreover, the comparison of microspores in coals has recently been applied to the identification of seams in Great Britain (228).

DIMENSIONS AND MOVEMENTS OF BOTANIC DUSTS.

The size of spores is generally greater than 12 micron diameter, and lycopodium spores are of average diameter about 30 micron, and weigh about 10^{-8} gram. Pollen grains are larger than spores, being generally greater than 25 micron diameter. Seeds, of course, will be much larger than either.

But size is but a co-factor with weight in determining the relative wind-carry. Thus spores, dust seeds, winged and plumed seeds, winged and plumed fruits, woolly seeds and fruits, and even some weeds (which shed their seeds whilst travelling) will be carried by winds—but for varying distances.

As with lifeless dusts, the winds, in fact, exhibit a sorting action. The lightest are the spores of lichens, mosses, fungi, ferns, algæ, lycopodiacæ, and all vegetable cryptogams. Their weight is of the order 10^{-8} gram, whilst the weight of various seeds given by Grattarola are $3 \cdot 5 \times 10^{-4}$, $2 \cdot 8 \times 10^{-5}$, $2 \cdot 0 \times 10^{-5}$, and $5 \cdot 6 \times 10^{-6}$ gram, or about 6×10^{2} or more times the weight of spores. Since the wind can carry large pebbles 62 miles, and the coarser volcanic dust of, say, 10^{-3} cm. radius 10^{3} miles spores (of much less specific gravity than, say, siliceous dust) and probably the lighter dust seeds and winged seeds (which may be flat) must be classed with the finest volcanic dust, which tends to keep circulating round the earth rather than settling.

And whilst a lifeless particle may travel for indefinite ages with long-quiescent intervals wherein it has, somehow, escaped the importuning wind, a life-bearing particle is likely to complete its travels in one uninterrupted journey—if it has eventually grown. Near the ground, on steppes, deserts, dunes, roads, and other open spaces, spores and seeds are carried great distances. The important significance of the long-distance travel of spores is shown by their supposed instrumentality in bringing life to the earth. Thus Kelvin suggested that life first came as a meteorite-carried spore from some other world—since spores can survive the most intense cold and remain vital for great lengths of time. The spore could be embodied in the meteorite centre and avoid frictional disintegration. More striking still is the suggestion of Svante Arrhenius that spores, without supporting medium, could be propelled from planet to planet comparatively quickly by the pressure of light—previously discussed.

In deserts, spores and seeds, once finding damp, low location (due to subterranean springs) where they can germinate, the resultant plants filter more and more continuing seed and spore accessions from the winds. Wadys are thus formed.

Erratic surface winds will become less so with increasing height, and experiments carried out by C. F. Talman (229) by aeroplane having shown that black rust spores are found as

high as 10^4 ft., taking two days to settle in still air (527), spores are likely to be circulating in regions of steady wind pressure. The radius of such rust spores (from the application of Stokes' law) will be about 13 micron, and that of others is, say, from 12 to 30 micron. Botanical dust, therefore, if size alone were the criterion, would not fall within the finest staubospheric complement, and in still air would tend to have rather vertical than horizontal mobility. Thus A. M. Williams has shown (231) that it is the ratio of surface to mass—not merely linear dimension—that is the criterion of particle suspension in the formation or persistence of a dust cloud. This, of course, makes density an important factor, as already shown. But since high winds probably often travel 10^3 miles or more per day, spores will, in any case, be deposited from great altitudes in far-distant regions.

The constant "rain" of minute spores falling everywhere, and the fact that many of the lowest spore-producing plants are so abundant that their spores swarm in the air, such swarming presence in many parts being instanced by the rolling of seeds (hence probably spores) over the Libyan Desert in April sandstorms—H. N. Ridley (230)—H. H. Thomas (232), 25% of plants springing on glacier-vacated soil being from wind-carried seeds or spores—Vogler (233)—and the dispersal of seeds in the Swiss Alps, the carrying of spores by icebergs whence they are sea-deposited or passed to other lands, the fact that terrestrial algæ spores were the first to settle on Krakatoa after the eruption, and the interesting flow of spores and seeds over ice surfaces in arctic regions. Thus Sherard Osborn (234) states that "seeds of poppy, willow, and saxifrage were detected, solitary travellers constantly frisking over the frozen floe surface, sometimes rolling over, sometimes lurking behind a hummock, sometimes moving at a height of several feet." He noticed 4% spores and 96% seeds, fruits, berries, etc. It has also been observed that closely-related plant species may be confined to mountain tops which may be 2×10^3 miles apart. Thus Beccari (235) states that in Malay in the west monsoons the strong constant winds might carry small or winged seeds (e.g. rhododendrons) from west to east, and Baecken, east to west from Australia. A plumed seed, *and its descendants*, travelling in 25-mile flights, with consecutive yearly intervals for growth, could reach China from England in 370 years, and a tree like senecio (found in Pliocene

period) could overspread the earth in 10^4 years—H. N. Ridley (230). Pollen grains, by airplane tests, have been shown to be numerous at 15,000 ft. (110).

Pathogenic bacteria which infect vegetation with diseases and growths are doubtless wind-borne all over the world. J. Baxendell and A. R. Yarwood (236) reported a thick yellow-ochre-like deposit of algæ—not recognizable when dry—which fell as dust at Southport, England, in March, 1930, covering an area of 10 square miles, whilst Yarwood observed a redder deposit—another member of the same family of algæ—in Norfolk in 1917. Previous occurrence of such particles in Owen's jet dust counter records (237), since occurring in March, had been supposed due to mould from dead leaves.

Smut, bunt, or dust-brand is, of course, a well-known fungus, infesting grasses, cereals and flowering land plants, its numerous spores being almost black in colour.

BOTANIC DUST COMPLEMENT OF THE STAUBOSPHERE.

The botanical life-bearing complement can be regarded as being co-extensive in space, if not quite in time, with the remaining staubosphere, and hence probably, with the atmosphere. But there is doubt as to which staubospheric size zone spores, and perhaps winged, flattened, or plumed seeds, will belong. For, whilst a quartz particle—say, from a volcano—weighing 10^{-8} gram may have a radius of 10 micron, a lycopodium spore of that weight may have a radius of 30 micron. Owing to the hairy surface and porous nature of such spores (the pores containing organic material which may vaporize), they may probably behave like smoke aggregates, their apparent radius suggesting the obeying of Stokes' law, but their effective radius and density really causing them to obey Cunningham's law. In this latter case they would have horizontal rather than vertical mobility, and far greater tendency to remain suspended and travel continuingly in the world-wide circulation. They would be more likely, therefore, to serve more freely the tropical heavy precipitation regions, where, however, they will in any case be carried in large numbers. They will, however, be drastically distinguished in occurrence from the lifeless staubosphere by having much more pronounced maxima and minima numerically, owing to seasonal variations.

OTHER DUSTS AFFECTING BOTANICAL LIFE, AND INCIDENTAL DUST THEREFROM.

The case of the general dust of the atmosphere also enters largely into the botanical field, e.g. by way of the effects on plant and tree growth, and visible appearance of leaves and stems, by the greater or less deposition in stomata, on bark, etc., reaching an unpleasant and growth-arresting maximum in smoky districts (*cf.* Cohen and Ruston (213)), and the gradual burial or elevation of vegetation in particularly dusty regions (*cf.* Dust in Geology).

Special dusts are also used beneficially on vegetation, being blown on when necessary, to kill blight. This application of sulphur is recommended particularly, as, where in glasshouses sulphur is burned instead as a fumigant, W. H. Read and O. B. Orchard, of Cheshunt Research Station, have found that the fumes combine to form zinc sulphate, which washed on to certain plants, poisons them. Meller (197*b*) concludes, however, that injury to vegetation by smoke and soot is chiefly on account of the accompanying ash, tar and gases, as only a small percentage of stomata are actually clogged. Soot also is beneficial for the soil, whilst flue dust has its uses (516).

The incidental dust formed by vegetation is immensely added to by the disintegration of leaves, etc., in winter gales. On January 7th, 1934, a 60 m.p.h. gale swept Northern England. In any district covered, millions of dead leaves—shrivelled, with turned-up points—were carried in every direction by the gusts. Large amounts of dust must have been formed therefrom, either in contact with the ground, or loosened there, then severed by the wind when the leaves were in mid-air.

CHAPTER X

DUST IN INDUSTRY AND TECHNOLOGY

THE study of dusts in these two important fields, though not, of course, coincident, warrants joint classification on account of the close alliance. In those cases where industry and technology are totally coincident, the former, thus subject to maximum scientific control, incidental dusts will be least produced, and the industrial aim—where dusts are being manufactured—will be the exclusive production of utility dusts. In those cases where technology is divorced from an industrial aspect, the object is likely to be the study, rather than manufacture, of dusts, either utility or incidental. Whilst, where industry is divorced from a technological aspect, even though the industrial motive is not the production of utility dusts, the bye-production of incidental dust is likely to be a maximum.

SECTIONAL SUBDIVISION.

The section can be most suitably divided into :

(1) INCIDENTAL, casual, or bye-product dusts due to manufacturing processes, and generally undesirable, and

(2) UTILITY dusts, manufactured and produced as dusts, for consumption.

Whilst the latter will generally be submitted to some scheme of size determination and distinction, this will not be applied to the former, any given sample of which will, consequently, probably cover a larger size range, being thus more heterogeneous.

(1) INCIDENTAL DUSTS.

Incidental dusts will be produced in practically all industrial pursuits whatever the particular industrial product(s) of the particular industry. For, whilst dusts are constantly produced

by general activities (*cf.* previous sections), the concentrated effort of industry as factory-organized, with the massed human activation, concentrated mechanical and machine effort, and constant handling of raw and finished materials and products, will greatly accentuate and concentrate the incident dust production. Varying amounts of such dust will permeate factory air and workshop air, its visible appearance depending on colour of dust and size and shape of particles, according to W. E. Gibbs (248).

Nuisance Dusts and Dangerous Dusts.—Such industrial incidental dusts can all be classified as (*a*) nuisance dusts, or (*b*) dangerous dusts.

(*a*) *Nuisance Dusts.*—This class is that of all industrial dusts most likely to be ignored. It will be variable from time to time in the same place, though, in some industries such as textile, and photographic material manufacture, the air must be free from dust. It may include dusts which, treated by modern scientific processes, e.g. electrical precipitation, become a valuable bye-product. It is the kind of dust which accounts largely for the huge colliery spill banks, the deep iron scale dust on smithy floors, the anthracotic miners' lung and daily blackened exterior, the thick moulding sand and metal dust on the steel foundry floor, the trodden-in metal dust of the working jewellers' floor (valuable withal), the artificially albino appearance of the miller, or the fibrotic lung of the silicotic. Where, as in the last-named case, it is pathologically dangerous, it will be considered in the next section. Generally, except where it may have bye-product use, it is discarded as rubbish. It goes to swell the huge output of refuse dusts.

(*b*) *Dangerous Dusts.*—This class includes all incidental dusts which are dangerous physically, rather than physiologically—e.g. by forming by dispersion in air a highly combustible aerosol, or by generating a sparking electrical potential which could initiate explosion or combustion. Owing to their intriguing, but awesome, potentiality, such dangerous industrial dusts which cover a wide range (and include many utility dusts) have received considerable attention. Thus R. V. Wheeler (36) studied sixty or more dusts and powders used in mills and factories, and compared their combustibility; W. E. Gibbs (248) has devoted a small volume to their consideration; P. Beyersdorfer (133) has made a particular study of the dangers of sugar dust; R. V. Wheeler (249) of coal dusts; Jaeckel

(250) has calculated the relationship between spontaneous electrical charge, degree of dust dispersion, and explosibility; D. J. Price, H. H. Brown, H. R. Brown, and H. E. Roethe (251) have collated numerous instances in the U.S.A. of disastrous dust explosions; G. S. Rice, H. P. Greenwald and H. C. Howarth (418) have studied the effectiveness of different-sized rock dusts in preventing mine coal-dust explosions; and Edwards and Harrison (419) have studied the oxygen concentration for explosion prevention in dusts. Similarly, L. J. Trostel and F. W. Frevert (252) have discussed the lower limit of concentration for explosion of dusts in air, for various substances such as starch, wheat, sulphur, sugar, aluminium and coal. Price and Goodenow (35) have compared dust and gas explosions; Price (37) has shown that some dust mixtures ignite more readily than gaseous explosive mixtures; Brown (38) has shown that the finer various carbonaceous dusts, the nearer the approach of flame velocity to that of gas explosions; Dedrick, Fehr and Price (39) have dealt with grain dust explosions in attrition mills; J. S. Haldane (40) has discussed the use of shale or stone dusts to check dust explosions, and (43) the impractibility of diluting factory air with flue gas to prevent dust explosions; Brown and Clement (41) that grain dust will not explode with an air-oxygen content of less than 12% (coal dust needs at least 14%); and Harger (42) has discussed dust explosion prevention in factories or mines by diluting the air with flue gas; Sinnatt and Slater (253) the propagation of a zone of combustion in powdered coal; Allison (254) has studied the explosibility of coal and other dusts; Taffanel and Durr (255) and Morgan (256) have studied dust explosions.

The bizarre and insidious manner in which dust may give rise to explosions is witnessed (1) by the explosion at Freyming Colliery, Sarr et Moselle coalfield (*Annales des Mines*), due, probably, to a rust fragment from compressed air which settled between expansion valve and seat in a compressed air locomotive; (2) the explosion of sulphur dust in a sulphide works due to incandescent iron sulphide on chamber walls in a vulcanizing plant, and again in the Claus kiln of a carbon bisulphide plant (259); and (3) in single roll grinding mill where grinding blocks were pressed against roll. The minimum vent area desirable in compartments used in the food industry has been determined by the study of explosions caused in

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compartments of different shape and size, with windows and swinging vents in various positions (260).

It is obvious that, of all dangerous dusts, the majority will be incidental. For the dangerous utility dusts, being the aim of the industrial process, rather than its incidental accompaniment, will be so controlled as to obviate danger. All save those of chemically explosive nature require dispersion into sol form before becoming dangerous, whereas the end of almost all industrial dust production will be the gel (or undispersed in air) form. But, amongst the incidental dispersed aerosols, of which, according to W. E. Gibbs (258)—who gives the average mgms. per c.m. in certain working conditions, and the average number of dust particles per c.c. of air—industrial atmospheres may contain 30 mgm., and sometimes up to 400 mgm., of dust per c.m., the degree of danger—*mutatis mutandis*—will vary with the chemical nature of the dust itself both directly and indirectly. Gibbs (75) gives 32 gm. per c.m. as the lowest concentration for coal dust explosion in air, whilst carbon black may propagate flame up to 394 gm. per cubic metre.

Relative Combustion Hazard of Dusts in Industry.—To compare this relative hazard (even when a dust whose production is aimed at becomes dispersed in manufacture, it may be regarded, to that extent, as incidental), the standard of comparison determined by R. V. Wheeler (36) may be adopted, as shown in the table.

TABLE V

Manner of Comparison of Ignitibilities of Dusts According to R. V. Wheeler

Class.	*Igniting Source.*	*Ignition.*	*Propagation.*
1.	Small, e.g. lighted match.	Facile.	Facile.
2.	Large, e.g. bunsen burner flame.	Facile.	Requiring large or high temp. heat source.
3.	——	Difficult.	Difficult.

(N.B. Phraseology, but not meaning, has been modified.)

Perhaps those dusts falling into Class 1 may be regarded as "dangerous," since those of Class 2 require special conditions for combustion propagation. Class 1 comprised 24 of the 60 dusts tested, and includes such materials as sugar, starch, dextrin, cocoa, wood flour, flour (flour mill), maize, and tea.

It will be realized that such dusts, on account of (*a*) their intrinsic danger, and (*b*) their extent of production, are liable to be very dangerous. On this account such dusts have become the object of special technological and scientific study. The most dangerous dust, par excellence, however, is coal dust.

Coal Dust one of Maximum Danger.—Coal dust is most dangerous because, in addition to (1) its combustibility, which determines the " winning " of the parent material, (2) its extent of production is immense and basic, (3) its occurrence is in conjunction with a dangerous explosive atmosphere, very often, and (4) it envelops confined and subterranean operations which render the operators a relatively easy prey to its danger element.

Whilst, therefore, keeping in mind the danger of such dusts as sugar, flour, starches, etc., it is desirable that most attention be given to coal dust—the outstandingly dangerous incidental dust example. For the above reasons coal dust has become the object of extensive and profound technological and scientific study *per se*, with the object of mitigating, then eradicating, the constant loss of human life attendant on its continuous production, which, to a great extent, is responsible for such tragic figures as follow (257) :

	1930	1931
Total of killed in all coal and metalliferous mines in Great Britain ..	1,025	869
Total of injured in all coal and metalliferous mines in Great Britain ..	167,501	142,194

Whilst coal dust has not always been recognized as a sourcee of danger, the most important work in this country aimed at the now-acknowledged danger is that of the Safety in Mines Research Board, who maintain large laboratories at Sheffield, in proximity to the University, and a fully-equipped Experimental Station at Buxton, Derbyshire. Other countries perform similar work, e.g. the Bureau of Mines in U.S.A. ; l'Institut National des Mines in Belgium ; la Station d'Essais, Comité Central des Houillères, in France ; Germany, Austria, Czecho-Slovakia, South Africa, Canada, Australia, and India, and a scheme of international comparison of data and results is in operation, which has led to an International Conference on Safety in Mines at Buxton (England) in July, 1931 (Safety

in Mines Research Board Paper, No. 74, H.M. Stationery Office). An excellent survey of the work of the S.M.R.B. was made by Prof. Jocelyn F. Thorpe at an evening session of the 1933 (Leicester) meeting of the British Association.

Epitome of Safety in Mines Research Board Publications of Dust Danger Research.—Whilst the numerous publications of the S.M.R.B. by H.M. Stationery Office set forth the results of individual investigators on numerous problems, those dealing with dusts from the viewpoint of its danger are here only applicable, and will shortly be considered.

The conclusions date from 1923 and continue to the present, including Papers No. 3 by R. V. Wheeler (261*a*) describing coal dust explosions at Eskmeals, Cumberland; No. 13 by G. S. Rice and R. V. Wheeler (262), concerning stone dust as a preventive of coal dust explosions; No. 14 by H. P. Greenwald and R. V. Wheeler, on the effect of pressure release on coal dust explosions; No. 31 by A. L. Godbert (269), on laboratory methods of determining inflammabilities of coal dusts; No. 33 by T. N. Mason and R. V. Wheeler (264), concerning the effect of chemical composition of coal dust on its inflammation; No. 48 by T. N. Mason and R. V. Wheeler (265), studying the relative inflammability and explosibility of coal dusts; No. 56 by A. L. Godbert and R. V. Wheeler (266), being a laboratory study of the relative inflammability of coal dusts; No. 63 by H. E. Newall and F. S. Sinnatt (268), concerning propagation of combustion in powdered coal; Nos. 62 and 70 by M. J. Burgess and R. V. Wheeler (267, 271), on the ignition of firedamp by the heat of impact of hand picks and coal cutter picks against rocks; No. 64 by T. N. Mason and R. V. Wheeler (270), on the effect of presence of firedamp on the inflammability of coal dusts; No. 73 by A. L. Godbert (272), on the combustion of coal dust; and No. 79 by T. N. Mason and R. V. Wheeler (272*a*), on the relative effects of different "stone dusts" on the inflammability of coal dusts.

Most of the large-scale conclusions have been arrived at from experiments in a gallery of 7 ft. 6 ins. diameter formed of boiler sections rivetted together to simulate a coal mine gallery. Various "stone" dusts, for example, powdered Fuller's earth, which are non-combustible and arrest coal dust inflammation, have figured in some of the experiments; The outstanding feature of all the experiments is the tacit realization

of the dangerous combustibility of coal dusts, so that studies of the varying degree of this condition under varying conditions, and amongst varying coals, are the questions determined. Thus in Paper No. 33 the arrest of combustion in dusts of different coals by mixed incombustible dust is shown to be related to their respective content of volatile matter. Also, by the adoption of a " fineness factor," a tentative correlation between inflammability and electrical charges developed by dusts of different coals (127) dependent on ultimate particle fineness, is shown.

Again, Paper No. 48 discusses the order of inflammability of seventeen different coals as measured by maximum pressure development, and with this is correlated their order of explosibility, and the determinations of Paper No. 33. It is shown in No. 64 that for each 1% of firedamp added to the air in which seven different coal dusts were fired, the proportion of incombustible dust required to suppress inflammation must be increased by $\frac{100-S}{6}$, where S equals least proportion of incombustible matter required to be mixed with coal dust to suppress inflammation. Nos. 56 and 73 may be regarded, respectively, as a laboratory study coincident with the large-scale inflammability experiments, and a photographic examination of the mode of inflammation of coal particles. It is determined in No. 14 that the effect on explosions in a closed tube is to increase their velocity if openings are placed ahead, and to decrease velocity if openings are placed behind. Rice and Greenwald (514) have shown that the lower concentration limit of 200-mesh Pittsburgh coal for mine explosion propagation is but about 0·05 oz. per cubic foot—an amount only detectable by careful examination. Paper No. 33 contains a useful bibliography chiefly dealing with coal dust explosion, and presents a historic survey of its subject, whilst Nos. 62 and 70 discuss the possibility of mechanical sparks (probably incandescent dust particles) leading indirectly to dust explosions.

(2) UTILITY DUSTS.

Of the vast field of utility dusts, many are dangerous both physically and physiologically dispersed as sols. Those of Class 1 in the foregoing table are examples of the former, and practically all dusts containing silica, of the latter. Again,

some utility dusts, e.g. those containing lead, chromium, or yellow phosphorous, are chemically and physiologically dangerous as poisons without dispersion, through the stomach, whilst irritant action, as in the case of sickness due to sand in troops in Egypt and Mesopotamia during 1914–1918—W. E. Gibbs (274)—may arise merely mechanically.

Coal dust, until recently a merely incidental dangerous dust, has now become a definite utility dust as a dispersion, with oil as colloidal fuel, or otherwise. This revolution is witnessed by the colloidal-fuel-fired Atlantic crossing of the S.S. " Scythia " in 1932, when no stabilizer was used to keep the coal particles dispersed in the oil, but special oil of high fixed-carbon content was necessary for this purpose.

In the industrial dust sphere this transition from incidental to utility dusts marks the path of scientific progress.

Another important field of its operation is that of the new industry of residual processing or clarification whereby " waste" materials such as clinker, formerly constituting incidental dusts (on disintegration) are treated and marketed for utility purposes, and present trends in dust recovery are discussed by E. P. Partridge (416). It is interesting to note that the now-recognized danger of coal dust in mines has created a special dust utilization to counteract such dangers, viz. " stone " dust. This is dealt with by A. Greenwell (261). Increasing utility fields are being constantly sought for treated waste dusts. Other, quite different, but very important types of transition, are (*a*) that which hydrogenation is likely to facilitate in converting sawdust into, say, sugar ; (*b*) the production of moulded shapes, of strength equivalent to the natural block, from soapstone dust treated with sodium silicate—J. G. Phillips (273) ; and (*c*) synthetic stone from shale and slate with calcium oxide and superheated steam, for production of tiles and paving materials.

The Immense Range of Utility Dusts.—There is a vast scattered bibliography concerning industrial utility dusts, and a constant flow of articles thereon in scientific and technological periodicals.

Industries where dusts are the end of manufacture, or useful in promoting that end, may almost all be found in " Occupation and Health " (196), though even this may probably not be exhaustive.

Such dusts—whose exhaustive consideration would be out

of place in this monograph—can be roughly divided into: (1) Edible (2) Cleansing (3) Habit, medical or decorative, (4) Process, manufacturing, or basic. Much information about industrial dusts—more particularly in the sphere of fuels and power production—was elicited in papers given before the various World Power Conferences in different countries.

The ever-increasing range and intricacy of application can be exemplified by reference to the extensive industry of edible dusts. Thus rice and wheat are now marketed in "puffed" condition, the respective berries being enlarged to 8 × normal size, their coats and shapes remaining unaltered. This transformation is achieved by non-mechanical pulverization into fine particles, of the enclosed starch by steam (from berry moisture) internally generated at 550 degrees F. for 40 minutes, under pressure imposed by an enclosing bronze "gun"—on firing the "gun." Thus large amounts of utility dusts are prepared internally and secretively, facilitating easy attack on their starchy substances by digestive juices. The biological significance of many industrial dusts is thus exemplified, just as their communal hygienic significance is indicated by the tremendous smoke and dust output from industrial chimneys, and their pathological significance by the physiological effects of many on industrial workers.

The complete consideration here of all industrial utility and incidental dusts being impracticable, those chiefly occurring in a given case, say the steel industry, may be briefly discussed.

The utility dusts used in steel manufacture are chiefly various kinds of sand, including sand for moulding, for sand blasting, and fine crushed sand for "fritting," i.e. filling of holes from which molten or semi-molten metal has been scraped in the hearths of Siemens' acid furnaces. To these must be added fine coal or carbon dusts "dusted" dry on to mould surfaces before casting to prevent sand adherence, or similar dusts together with clay applied wet as "blacking." The incidental dusts formed are used moulding sand (often made from crushed bricks, and, therefore, probably containing fine clay particles less than 5 micron diameter) mixed with oxides of iron (scale), mixed metal and sand dust from sand blasting, and a much harder metal scale dust than this from steel shot blasting. Considerable dust is also evolved from producer gas towers when these are submitted to the stirring and breaking of internal "scaffolding" of coke and small coal, coal dust, etc.,

such dust being formed by the fan draught passing through the coke mixture. Incidental dust is also formed by spark showers when casting or welding, and from scale in forging, fettling, hammering and rolling.

There are, of course, many other less-pronounced ways in which both incidental and utility dusts enter into the process, e.g. wood dust from pattern shop, or dust from fluxes, before use.

It is worthy of note, in passing, that despite all these dusts, the outstanding incidence of pneumonia in the steel industry discussed by Brundage and Bloomfield (508) seems not to be due to them, but to the very rapid temperature changes suffered by workers—though moulding sand, for example, contains about 79% of silica (513).

Technical Study of Individual Dusts.—The application, use and production of each of the above dusts will probably have its own bibliography, e.g. sand blasting. This, of course, applies to numerous other dusts. Thus, in the coal mining industry, where dust plays so huge a part, the coal dust incidence problem, technologically, physically, and physiologically, has been studied by Payman and Statham (275), and K. N. Moss (275*a*) has dealt with gases, dust and heat in mines, whilst such a relatively small consideration, from the general viewpoint, as the removal of coal dust from coal surfaces before washing, has been carefully dealt with by W. R. Chapman and R. A. Mott (276). They discuss such points as the friability of the coal in regard to the amount of dust produced, the constituent coal substances from which dust is produced, the kinds of dust which elude washing in relation to the machinery used, and so forth. Henry Louis (277) and R. C. R. Minikin (278) recognize dust removal before slack washing as one of the most difficult of problems. Railway companies are increasingly installing apparatus for minimising coal breakage and dust production in freighting vessels at ports, its previous lack having largely checkmated the costly process of screening and cleaning at the pits.

Methods for Removing Dust.—There are many types of dust cleaning plant, the respective principles being typified by (1) the Humboldt system—dust removed by vibrating screens; (2) dust removed by falling separation; and (3) the Meguin system—dust removed by combined screening and air blast. A froth flotation method is now being successfully developed

using an emulsion of oil and water to separate the coal dust—which floats—from refuse dust, which settles. Improvement has recently been made in dust arrest in bagging and grinding plant in cement works, though no efficient means is yet devised for trapping zinc fumes (259). Recently, R. A. Mott (279) has concluded that when the reduction in efficiency of the use of coal exceeds, say, 6d. per ton, the reduction of the ash content by coal cleaning is desirable.

THE CONVERSION OF INCIDENTAL INTO UTILITY DUSTS.

This important and increasing salvage principle forms an independent and highly technical study in industrial dusts. Utility here may be extended to mean hygienic as well as commercial. In fact the conversion has as its object either or both (*a*) to avoid physiological complications in interior workers, e.g. by exhaust ventilation of siliceous particles as in grinding; (*b*) to avoid unhygienic effects on the exterior public, e.g. by precipitation of chimney stack dusts; (*c*) the complete transformation of an incidental to a commercial utility dust, e.g. the innovation of pulverized fuel; or (*d*) to combine (*b*) and commercial realization of bye-products, e.g. the electrostatic precipitation of lead fume.

The subdivision (*a*) will be considered in the section Dusts in Pathology, etc.

The Conversion (*b*).—The conversion (*b*) is relatively recent. There is a huge field for its exploitation, particularly with regard to the arrest of atmospheric pollution by the tarry smokes of domestic chimneys. Electrostatic dust separation is already used in the de-tarring of carbonization gases, and cleaning blast furnace gas, whilst the emphasis placed on the superiority of electrostatic precipitation over cyclone methods or washing in the recent report of the Electricity Commissioners (146) indicates the huge conversion field provided by power stations and manufacturing plants. Some extent of its immensity is suggested by the statement that often 75% of dust particles less than 10 micron diameter comprises 50% to 70% of the coal ash contained in 5×10^5 to 6×10^5 cubic feet of gases per ton of coal burned—such particles being hard to remove (280).

The case for centrifugal method efficiency is put by J. W. Gibson (281), advancing the advantages of a patent dust collector, who states that the rate of fall of the dust particles

(varying from 24·9 ft. per second for particles of 10^3 micron to 0·007 ft. per second for particles of 1 micron) is the most important problem in the consideration of flue dust gas, and that over one hundred power stations are already equipped with this centrifugal type, which will remove 85% to 95% of the total flue gas content from over $1 \cdot 5 \times 10^5$ tons of dust per annum.

Valuable information on the industrial treatment of fumes and dusty gases is also given by W. E. Gibbs (282).

The Conversion (*c*).—The transformation (*c*) provided by pulverized fuel is quite recent and quite immense in importance and repercussion. Coal dust, recently completely incidental, dangerous, and a nuisance, is now of so great utility importance that it provides statistics in that rôle (283) which show 3,672,750 tons of pulverized fuel used in 1932 in Great Britain, 1,200,000 tons of which was used in electrical undertakings. Whilst its use for boiler firing provides a greatly increased dust production, to be dealt with under (*b*), its use in cement kilns (1,346,763 tons) has become doubly utilitarian, for, in addition to its fuel use, its ash forms a desirable constituent of that immense industrial dust product—cement. Excepting cement works, 112 undertakings are utilizing pulverized fuel with a grinding cost varying from 1s. to 5s. or 6s. per ton, or more, at which figure economies are still realized. For industrial steam raising, particle size is such as to allow 65% to 80% to pass 200 I.M.M. sieve, and for metallurgical purposes, 85%. Whilst the convenience, heat control, and combustion are equal to gas or oil, and the economy greater, the initial cost of new installations has heretofore discouraged a maximum turnover from hand firing in Great Britain, though in Germany and U.S.A. this has been overcome for several years by centralization of production and distribution of the fuel. Centralized production has only just become available in Great Britain, a move which is expected to encourage rapid turnover to pulverized fuel use, both from hand firing and from oil firing, since equipment for the latter will, probably, be available for dust—representing the cheapest means of controlled heating. With increased demand for pulverized fuel, the price is likely to fall further, and this erstwhile incidental dust is likely to introduce a revolution in all industries.

Particulars of pulverized fuel firing are given by S. H. North (284) and "Pulverized Fuel Firing: with Special Refer-

ence to Power Station Practice," by S. B. Jackson (285), whilst in " Fuel Economist " R. A. W. Connor (286) discusses the testing of pulverized fuel.

The Conversion (*d*).—This is now probably the widest-used method of conversion, and electrostatic precipitation is probably the greatest example, though cyclone separation, and washing, are still used.

Electrostatic precipitation, first noted by Guitard (53), Tissandier (54), Dieudonné (55), and Hohlfeld (52) is now in wide use for separating liquid or solid particles in chemical, smelting industries, etc. O. Lodge (21) was the practical pioneer of this process (though its principle was discovered over a hundred years ago), being obliged, in the course of his researches, to await the sufficient-current production of high voltage generators. He worked with J. W. Clark from 1883, and in 1884 demonstrated the application before the British Association Meeting in Montreal. His sons continued the work, and the Lodge Fume Deposit Co. was formed. In Germany and the U.S.A. the subject had been independently developed by Erwin Möller and F. G. Cottrell (56), respectively. The firm of Lodge-Cottrell, Ltd., was a combination of British and American interests, and in 1930 world-wide co-ordination was established, leading to reduction in costs of installations. Ladenburg and Sachsse (420) and ver Eecke (421) have also studied the electrostatic precipitation of dusts from gases.

Over the world, more than a thousand plants have been erected in chemical and allied industries. Such materials as dusts and mists are precipitated in contact sulphuric acid manufacture, and valuable dust from arsenic, copper, lead, tin, and other ores, though the process is not applied to the trapping of zinc fumes, for which no efficient process is yet devised (259). Breyer (417) advances conclusions on methods of collecting dust in zinc and blast furnace industries. The basic principle of electrostatic precipitation applied on a laboratory scale is described by Drinker, Thomson and Fichet (288), whilst O. Lodge (289) and F. G. Cottrell (290) give accounts. Whilst this method employs a high-tension current, H. Rohmann (292), by means of low-tension precipitation, has analyzed the sizes in suspensions of very fine particles, although Drinker, Thomson and Fichet (288) seem to show that the high-tension method has not been successfully applied for analysis, but only for total mass determination. E. F. Burton

and B. M. Reid (293) have applied alternating electric fields to the determination of particle sizes in colloidal suspensions.

According to J. E. Lister (291), who also gives particulars of other electrical separation methods, one usual arrangement is a large number of 6-in. to 9-in. diameter pipes about 10 ft. long, carrying centrally-suspended chains or wires whose electrical charge promotes an electrostatic field in the pipes. The pipes are electrodes of opposite sign to the chains, and the whole is shaken periodically (period depending on rate of dust deposition) to shake dust down. The current supplied at voltages up to 100,000 is provided by a motor generator and transformer rectifier. Only about $1\frac{1}{2}$ to 3 kilowatt hours are necessary for cleaning 10^6 cubic feet of gas, and it may be noted that blast furnace gas contains from 0·15 gm. to 0·45 gm. of dust per cubic foot, such dust in the case of iron blast furnace gas containing 40 lb. to 100 lb. potassium per 10^6 cubic feet of gas, according to Chance (44). Whilst for special combustion in gas engines dust should be reduced to about 0·6 mgm. per cubic foot, i.e. practically absent, though more may be permitted for boiler firing, it is necessary to remove the dust for the former use, when the potassium is recoverable. In a copper smelting works where the plant has 640 pipes, 6 tons to 10 tons of dust containing appreciable copper, and much arsenic, is collected per day. In non-ferrous metallurgical smokes, which may be emitted at 10^6 cubic feet per minute, with 20 tons to 30 tons per day of material recovered, the necessity may arise of destroying acid fumes by neutralization, as well as collecting dust, according to Sprague (45) and Ebaugh (45). In a plant at a London power station over 78% of the dust collected in the hoppers passes 300 mesh sieve ("Fuel Economist," May, 1932, Advt.). Particles may be graded according to their conductivities.

The advantages of the electrostatic precipitation process include dry separation, constant separation efficiency, irrespective of particle size, minimum obstruction to gas passage, and no temperature reduction causing variation in draught.

A new method, to meet which a testing machine known as the Shirley analyser for raw cotton or waste is now marketed, has now been evolved for separating the dust and trash from fibre (528).

PREPARATION AND CLASSIFICATION OF INDUSTRIAL UTILITY DUSTS.

The production of dusts can be conveniently divided into: (*a*) Preparation from larger-sized units; (*b*) technical classification of dust produced; and (*c*) methods of determining particle-size classification of dusts.

Preparation from Larger-sized Units—(*a*).—This excludes such chemical or physical methods as aim at building up dusts (1) from chemical actions, either in solution, or from gaseous interaction; (2) from volatilization and condensation. For, in such cases, the dust-form of the product is generally of secondary importance. Such cases are the precipitation of substances by double decomposition, and the production of, say, ammonium chloride and gas carbons.

Dusts, desired as such, are generally produced by some form of disintegration of larger units, though owing to cohesional forces overcoming artificial disintegrating power, materials cannot be successfully pulverized by straightforward methods to less than 0·1 micron diameter—W. E. Gibbs (294). The implements used for disintegrating vary with the nature of the material, and the degree of fineness desired. Even those which disintegrate to a size limit well above that of dusts (*cf.* section Dust in Nature), e.g. crusher jaws for granite breaking, production of road materials, etc., will, however, produce dust incidentally. Thus the "Hecla" coal breaker is advertised as producing a minumum of slack.

Disintegrators which are also pulverizers adopt such means as moving steel balls, beating arms, rollers, revolving discs, concentric oppositely-revolved cages of open bars, mills with metal or stone rollers, or cone-shaped grinding units. Pulverized fuel—the underlying cause of whose economy is the immensely increased ratio of surface to volume due to pulverizing—has been known for about 40 years, and may be delivered to jets, by fans or compressed air before or after dispersion, by feed worm, etc. Generally, it should all pass 100 I.M.M., and 85% pass 200 I.M.M. sieves. It is thus of similar size to coal dust, regarded previously as solely a danger dust. Its utilitarianism does not, of course, cancel its danger proclivities, precautions against which are forcefully referred to by W. E. Gibbs (295). Its use reduces costs, provides more elastic operation, and utilizes low grade fuel, though its easier ash disposal aggravates the serious problem of atmospheric

pollution. Its annual world use is independently (*cf.* previous figures) estimated at $1 \cdot 5 \times 10^8$ tons, 1×10^8 tons being used in U.S.A. (296), and the fact that locomotives on the Brazilian Central Railway can use local low grade fuel, if pulverized, avoiding importation, indicates the kind of cause which is rapidly increasing its utility. L. C. Harvey (297) discusses American systems, and pulverized fuel, colloidal fuel, fuel economy, and smokeless combustion; R. A. S. Redmayne (298), pulverized fuel as a combustible; J. H. Biles (299), the question of fuel for ships; and J. Blizzard (300), the preparation, transportation, and combustion of powdered coal. It seems not to have progressed in use in marine boilers as much as in land boilers, partly because of the large size of combustion chambers previously thought necessary, and the consequent lack of relative motion between air and dust in the dispersion—probably limited by the speed of diffusion (301). But a "grid" burner, feeding primary air and fuel in thin layers with secondary air passing between the layers, the results of whose test is the subject of a Fuel Research Board Paper (302), gives flexible combustion and compact flame with fuel down to 21% volatile matter, with but 7% carbon in the ash. The importance of such dust shown by the above particulars is the measure of the importance of methods of preparation of dusts. Of the pulverized fuel now produced in Great Britain, about 50% is prepared in ball mills, and 40% in impact and beater type mills, though the proportion of the latter to the former in use is 3 to 1. The increasing efficiency of high speed mills is making the "bin" system unnecessary in this industry, and although the proportion of "unit" (i.e. binless) installations to "bin" installations is now 5 : 2, the annual tonnage of pulverized fuel is about equal for both (283).

Technical Classification of Dust Produced (*b*).—This classification is generally carried out by air separation, bag filtration, electrical separation, or washing, the method chosen depending on the characteristics of the dusts to be classified. All the air separation processes depend on the relation between particle size and specific gravity, and the air current velocity necessary to balance different-sized particles. The connecting formula is: $V = K\sqrt{D\,S}$, where V = velocity of air in feet per second, D = diameter of particles in inches, and S = specific gravity of materials, K being a constant of value 77 for approximately

round grains, and of different value for others. The air current may be applied horizontally or at an inclined angle. For such dusts as metallic oxides, cements, etc., settling chambers may be used, but cyclone separators require less space, though in American cement works, for collecting fine cement dust and passing through boilers and economizers, cyclones 40 ft. high and 20 ft. diameter are used—J. E. Lister (291). P. E. Landolt (323) compares the advantage of multicyclone collectors and Cottrell precipitators, and points to the bye-product potash recovery in the cement industry—a very dusty one. Cyclones have also been used for separating tar from gas retort gases. The air speeds necessary for conveying various materials are, approximately, 1,200 ft. per minute for sawdust up to 3,000 ft. per minute for wood refuse or grain, and 4,000 ft. per minute for fine coal dust. This method is discussed by Lee (45), Babu (46), and Hofman (47), and in articles in technical journals (48, 49).

Bag filters are used in cement works and for other fine dust separation. The sleeves or bags are generally carried vertically, in a metal framework, and shaken at intervals to dislodge the dust into a hopper. The method is used for de-dusting blast furnace gas, and the bags may be of wool, cotton, camel hair, asbestos, etc. The care of such bags is dealt with by Lindau (50). Towers filled with material such as coke have also been used.

Electrical separators are typified by the electrostatic precipitators already described. Some use powerful electromagnets where certain metal dusts or fragments are to be separated. In this connection, reference may be made to the liability of contamination of dusts by metal dust from the balls, when a ball mill is being used. In the grinding of dusts the peculiar possibility arises that the dust is likely to provide an incidental nuisance for the machinery, and a well-known firm advertise a " Patent dust-proof automatic weigher for pulverized fuel."

Thermal precipitation, discovered by Aitken (51) (see also Russell (51)) may be used, the dusty material being passed over cold surfaces, on which it would be selectively deposited.

As some smokes are difficult to wet (with water), e.g. from brass foundries, the washing system is very selective.

Methods of Determining Particle-size Classification of Dusts (*c*).—The chief characteristic of industrial dusts in general

required to be measured and determined is the particle size, although other physical qualities (largely dependent thereon), and chemical qualities in particular cases, are, of course, important. For example, for paint manufacture, 99% of solid constituents should be less than 10 micron diameter.

For anything but particle determination below, say, 60 micron diameter, sieves of mesh varying from 10 to 200 holes to the linear inch have given empirical satisfaction. The two accepted standards in this country are the "Cement" standard and the I.M.M. (Institute of Mining and Metallurgy) standard. In the former the wire diameter is half hole-side; in the latter they are equal, though since neither employ standard wire gauge sizes, P. E. Masters (303) proposes a third standard which shall. E. Audibert (304) suggests that in France three different sieving standards exist. But even in sieving dimensions, a dust sample passing through one sieve (say, 80 I.M.M.) and resting on the 100 I.M.M., will, of course, contain an unclassified range of particles between about 150 micron and 125 micron diameter. Some better method of separation and classification (though sieving is often indispensable) is, therefore, desirable even in those dimensions. Below 60 micron diameter, such means has probably been most effectively found in the elutriator. G. Martin, C. E. Blyth and H. Tongue (307), in researches on the theory of fine grinding, have studied elutriated samples from crushed sands to elucidate a simple law relating to the continuity of particle size in fine grinding, and the British Portland Cement Research Association has shown that, for a crystalline substance such as "standard sand," a definite law similar to the compound interest law does operate, when that substance is ground in a tube mill.

E. F. Greig (287) classes particle-size differentiation methods exhaustively as (1) optical, (2) sieving, (3) sedimentation, (4) elutriation (5) electrical precipitation, (6) bulk-density measurements (which have been used by the Engineering Standards Committee on cements as a fineness criterion); (7) measurements of heat of wetting; (8) measurements of angle of repose, and (9) filtering constants. The last four are empirical. Of these methods, Greig regards (6) of value as a criterion of air content of dusts and powders, and (4) as a sound method for obtaining dusts of given grade, or isolating component grades, though of small use for direct analysis. Combined with (1) and (3), (4) is regarded as suitable for

determining specific surfaces. Electrical precipitation is regarded as vitiated by the tendency of particles to create their own electrical charge, as shown by S. C. Blacktin (127). Greig (287) concludes, that with grades of dusts of definite ranges of specific surfaces, correlation of specific surface and inflammability of dust clouds can be provided by elutriation methods, and that, combined with sedimentation and microscopic examination, it can be used to analyze specific surfaces of dusts.

Bouton and Pratt (308) fully study the production of an elutriator, whilst Audibert in 1921 used a different design in connection with pulverized fuel plants, Blizzard (309) aiming at a formula for determining the terminal velocity of coal dust by its use, whilst W. Nusselt (310), at a German symposium on pulverized fuel, severely criticised the principle of Audibert's elutriator and Blizzard's dependent formula.

In the grading of materials for paint manufacture, the practice of elutriation is now regarded as essential.

STUDY OF THE SELF-ELECTRIFICATION OF DUSTS.

This question is dealt with in this section because self-electrification seems fitted to provide the basis of a means of distinguishing between very fine particle sizes, say, from 75 micron diameter downwards.

W. A. D. Rudge (306), first in South Africa, then in England, found that many dusts become electrically charged on moving through air. Millikan (11) found that oil, sprayed as fine mist into a chamber, was strongly charged thereby, and verified that this frictional charge was always an integral multiple of the electronic charge. P. Beyersdorfer (133), in Germany, found that fine sugar dust similarly created a high voltage charge, and that it might be ignited by sparks from a Siemen's ozoniser, whilst Jaeckel (250) experimented to ascertain the rarest dispersion of dust in air which could be spontaneously spark-ignited, producing the expression:

$$K = \frac{1}{cR}\sqrt{\frac{5H.dT}{4\pi}(ds_1 + cs_2)}$$

where k = charge in e.s.u. per gram dust; R = radius of spherical dust cloud in cm.; c = dust concentration in gram per c.c.; dT = dust ignition temperature − air temperature; H = mechanical equivalent of heat; d = air density in gram per c.c.; s_1 s_2 = respectively specific heat of air and dust in

calories per gram per degree centigrade. On the Jungfrau, A. Stager (134) experimented with driven snow dust, and concluded that the charge generated had one sign on the larger-sized particles; the other on the smaller-sized particles. Rudge considered the charges to be divided between the particles and the air, acidic particles being positively charged, and basic particles negatively charged, and, in general, that charge sign depends upon chemical characteristics, and is opposite to that of the ion of the substance in solution. A general theory correlating charge with chemical nature, and dielectric constants of media and disperse phases, has been developed by A. Coehn (496).

S. C. Blacktin (127) has shown that coal dusts, lignite dusts, lycopodium and starches generated considerable high voltage charges on a copper conductor when whirled through it by air; that electric sparks produced by such charges readily explode methane, propane and hydrogen-air mixtures; and that different coal dusts of the same standardized fineness (by sieving) generate charges of different dimension under the same experimental conditions. Four elutriated samples of a coal, of different particle size—all of which pass through 200 I.M.M. sieve—give different charges, the fraction of finest particles giving largest total charge—the others decreasing charge with increasing particle size. These results afford a basis for establishing the measurement of particle size by degree of electrical charge generated under given conditions. This differentiation has already been used in a preliminary sense by T. N. Mason and R. V. Wheeler (264) to produce a fineness factor amongst coal dusts which, according to sieving standardization, were of equal fineness. S. C. Blacktin and H. Robinson (126) have extended laboratory self-electrification studies of coal dust to large-scale field methods, and have found that very rare dispersions in air of coal dust (0·0011 oz. av. per cubic foot of 83·5% through 200 I.M.M. sieve dust), moving through a metal pipe at 45 ft. per second rapidly initiates over 4,000 volts, and that the electric sparks consequently drawn from the charged pipe readily ignite inflammable gases.

Whilst the possibilities of the pursuit of this subject are obviously immense, there is still considerable difference of opinion as to the mechanism of charge generation. Rudge (318), for instance, has evolved a dust electrical machine,

similar in design and principle to the apparatus used by Blacktin (127) on the small scale, and Blacktin and Robinson (126) on the large scale—both developed independently from that of Rudge—by which charges and sparks can be obtained from sand, road dust, flour, sulphur, iron filings, etc. Whilst the work of Rudge (306) and Blacktin (127)—who found that identically size-elutriated samples of two different coals (kindly supplied by C. M. Bouton of U.S. Bureau of Mines) gave different charges—seem to show that chemical constitution has some effect, and particle size is shown to vary inversely as magnitude of electrical charge by these workers and by G. B. Deodhar (312), the question as to the distribution of negative and positive charges is still unsettled. It seems unreasonable to suppose that, say, positive charge resides on "larger" particles and negative charges on "smaller," as first concluded by A. Stager (134) with snow dust, even by analogy with polar molecules, because in dust clouds, particle size will, generally, be roughly continuous. But when the particles are electrified independently, an observation of Cawood and Patterson (313) seems to show that sign is selected by particle size. On the other hand, V. E. Whitman (317), after photographing particle paths in an electric field, and concluding some negatively, some positively charged, and some neutral, finds that the change in ratio of positive to negative particles due to heavy-particle settling, is not due to large particles being oppositely charged from small ones.

G. B. Deodhar (312) and Hesecus (314) incline to the view that, unlike the conclusion of Rudge (306), charge sign depends, not on chemical nature, but is distributed between the parent body and the abraded particles, whilst P. Boning (315), confirmed by H. Israel (316), inclines to the view that the charging of particles by contact with larger similar bodies is due to a purely mechanical inertia effect of electrons, owing to the sudden strain.

Extending the theory of particle size selectivity, the gas molecules of the dispersion medium (e.g. air) may be regarded as being the smallest of particles, when this would account for one charge residing there, as distinct from residing on the smaller particles of the disperse phase. The opposing equal charge would then reside on the particles (no matter what size) of the disperse phase. This would explain the particular charge distribution, and would not exclude the theory of Rudge

(306) as to chemical nature and charge, which refers to a different phenomenon, viz. the sign of original charge on original substance (exclusive of the location of the opposite balancing charge in particular cases).

There still remains the question as to *how* the charge is generated, as distinct from where it comes to be located.

The earliest concept of frictional electricity seems to have been due to Gilbert (490)—1600—whilst Wilcke (491) in 1759 advanced a frictional electrical series, and Faraday (492), Riess (493), Helmholtz (494) and Hoorweg (495) were later workers. In addition to the view of Boning (315) and Israel (316) of a purely mechanical origin, it needs to be stated that in whatever manner electronic redistribution is brought about (i.e. charge created), the question of adsorbed, absorbed, or sorbed gas molecules or particles must be very germane to the problem—whether two solids, two dusts, one solid and one dust, one solid and gas, or one dust and gas, are the respective couples whose contact is giving rise to charge. H. S. Patterson (322) has shown theoretically that the fraction of charged particles should increase with time in slightly charged aerosols, but for initially highly charged ones, should remain constant, and has confirmed this for ammonium chloride and stearic acid smokes, and for magnesium oxide from burning magnesium. Though induction may play a subsidiary part, the main problem is part of the general problem of " frictional electricity " necessarily closely dependent on the question of adsorbed films. Thus, W. E. Gibbs (103) suggests that charge is possibly due to specific adsorption of gas ions on the particle surfaces, the existence of such adsorption being indicated by Schidlof and McKeehan (104), who find particle densities to vary with nature of surrounding gas, whilst Schidlof and Targonski (105) attributed lessening of apparent mass of falling particles to gas molecule bombardment, some of the particle surface molecules being replaced by gas molecules.

" Frictional electricity " is being thoroughly studied by P. E. Shaw (167) who, along with Jex (489) shows how charge depends almost entirely on invisible surface films, rather than on the visible bodies colliding, which rarely touch, whilst H. F. Vieweg (497) finds a film of moisture on one rubbing agent always confers positive charge the other agent being negative, and correlates this effect with Lenard's " Wasser-

fallelektrizitat "—whose positive complement is on the water, negative, on the surrounding air.

Deodhar (319) has worked on similar lines, and he regards charge on dust as of a frictional nature. V. Kohlschütter employs dust electrification to distinguish between "dust" and "true aerosols." P. E. Shaw (320) concludes "that the electrical nature of surfaces may change fundamentally when rubbed or struck, so that it is possible to obtain a positive or negative charge at will from solids. In a dust cloud we may expect some impacts to yield net positive, some net negative."

The films on particles are likely to be adsorbed gas molecules or micelles, and the practical reality of such adsorbed gases is indicated by the findings of P. Beyersdorfer that the pressure in an air-tight ball mill drops from atmospheric (760 mm.) to 23 mm. when 200 gram of lump sugar are ground therein, whilst its theoretical study, of course, forms an important physico-chemical field. So that it seems very possible that all spontaneous charges are due to the impact between the dispersion medium molecules and the gas molecules on the particle surfaces, possibly due to inter-atomic rearrangement. This would include the whole question with the generality now known to control chemical actions and the position of elements in the periodic table, i.e. the loss or gain of electrons from atomic orbits. The distinction being that, in the case of electrified dusts, kinetic energy is the immediate cause of the temporary orbital state.

The self-electrification of dusts moving in gases is, therefore, probably one expression of the electronic bias which, applied differently, makes certain elements chemically reactive until it is neutralized, but which accumulates to the piling up of opposite electrical charges in whirling dust systems.

If so, the possibility arises that whirling of definite dusts in definite gases might have the effect of making reactive such substances and gases as are, normally, chemically inert (having completed quantum groups including an outermost electron octet), by reducing or increasing the octet, and conferring reactivity. Attempts have often been made to induce inert gases to enter into chemical combination, and the bombardment of helium by electrons by Boomer in 1925 in presence of non-metallic or metallic elements—suggested as causing formation of the appropriate helides—would seem a similar operation to the creation of charge by whirling dust, with the advantage

that, in the latter case, the elliptic orbit of the metal (if metal dust were used) might also be activated. Since, as C. T. R. Wilson has shown (1), negative ions (with 1·26 expansion) are more readily condensed on to form rain than positive ions (with 1·30 expansion), and since, also, ordinary dust nuclei are the mostly suitable for drop formation, the combined desiderata suggest that dust particles in the atmosphere are likely to be mostly negatively charged. Since the charge will be largely generated by mutual ionization of air molecules and particle films in collision—the air molecules becoming " small " ions and the dust particles " large " ions—the air molecules will carry the corresponding positive charge. This points to the probability that dust particles, i.e. " large " ions, in the air, will be mostly negatively; air molecules, i.e. " small " ions, mostly positively charged. Which may well exhibit the fundamental principle of charge distribution in all moving dust clouds.

The possibility of electrification being caused by the sun cannot be entirely ruled out, for Hertz (473) found his inductive sparks facilitated by ultra-violet radiation from the sun; Huggins, in 1874, initiated the suggestion that the material of comets was electrically illuminated by solar radiation, and Blacktin and Robinson (126) found reduced electrification on the obscuration of solar light, which, however, was attributed to increased air humidity by clouds.

Whilst Blacktin and Robinson (126) found that the conditions in coal mines were such as to make it unlikely that high voltage spontaneous charges due to coal dust whirling could build up, so that the question as to whether spontaneous sparking was likely to explode coal dust hardly arose, D. J. Price (321) concludes that static electrical sparks will ignite grain dust and inflammable dust generally; Jaeckel (250) gives figures which show that inflammable dust of, say, less than 10^{-5} cm. diameter, may be likely to be ignited by their own spontaneous spark production, and Beyersdorfer (133) found that the charge of $8 \cdot 4 \times 10^4$ e.s.u., which one gram of finely divided sugar dust acquires on whirling, is sufficient to ignite a dust concentration of 1·57 gram per c.m. often obtained in conveyors or disintegrators. It should also be noted that, according to the researches of Hallwachs, Hoor, Righi and Stoletow (474), negatively-charged clean metal surfaces rapidly lose charge in ultra-violet light, but gather positive charge,

if originally neutral and well insulated. The apparatus of Blacktin and Robinson (126) was constantly exposed to ultra-violet light, but, it is worthy of careful note, practically none would reach any system in a mine liable to spontaneous electrification through dust.

CHAPTER XI

DUST IN PATHOLOGY AND PHYSIOLOGY: PNEUMOCONIOSIS

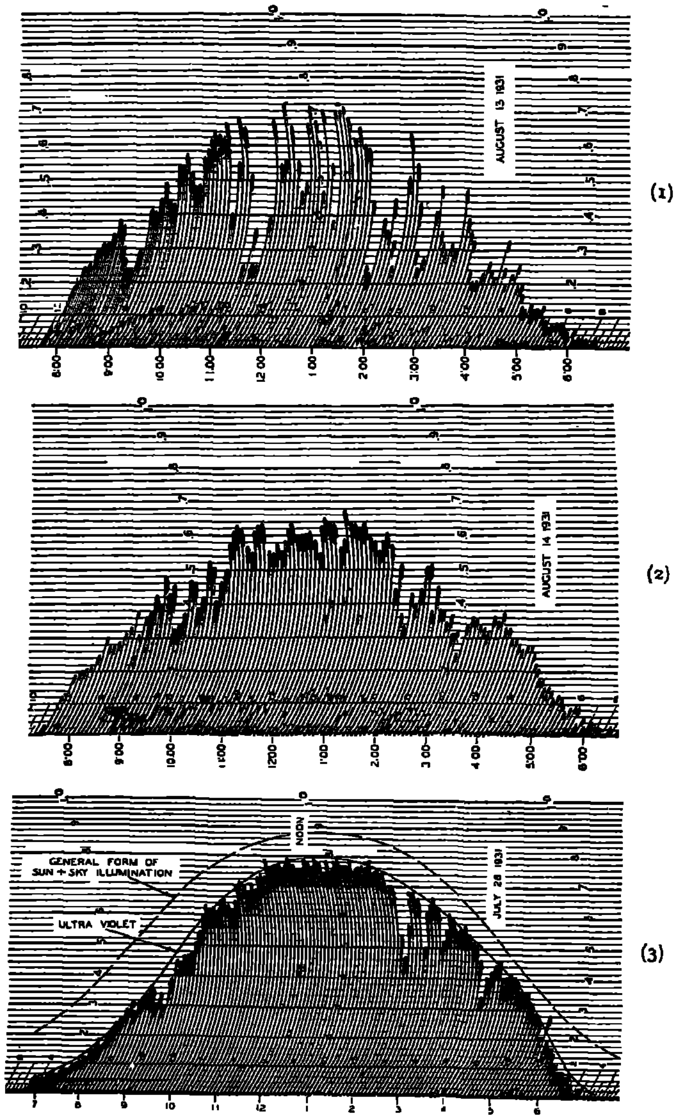
HISTORICAL.

THE incidence of dust in this sphere is chiefly a dangerous or unpleasant one. Such dusts as have medicinal value will have received generic consideration in the previous section.

Undoubtedly, the earliest serious interest of any kind in dust was taken in its pathological effects, which, by emphasizing his interest in its effects on the human body, underlines man's lack of intelligent interest in the study of dust for its own sake.

Probably the earliest published work is that of G. Agricola (324) (translated by H. C. and Mrs. H. C. Hoover in 1912), which considers the general pathology of metal dusts. Next, doubtless, comes an inaugural dissertation by J. Bubbe, in 1721, on the pathological effects of stone breaking, followed by a description of the peculiar disease which attacks sandstone workers (Leblanc, 325) and some account of a species of phthisis pulmonaris peculiar to persons occupied in pointing needles by Johnstone (326). This early start was succeeded by about four more articles before 1820; 14 between 1820–1840; 16 between 1840–1860; and 57 between 1860–1880.

In the early 19th century, the acute discussion regarding the pigmentary changes in some lungs was decided against the view that it was due to changing blood pigment, and that it was caused by dust particles being deposited after passing through the lymph channel. To the 91 contributions in the 80 years preceding 1880, about 1200 have been added in the 50 years succeeding, indicating the immense impetus which the subject has gained due to the serious health implications of incidental, rapidly increased dust production, both in scope and quantity, due to industrial expansion and needs.



[By courtesy of The Mellon Institute of Industrial Research, Pittsburg, Pa.]

Fig. 4.—The above comparative records of Ultra-violet Radiation received at the earth's surface from the sun, show respectively :

(1) Ultra-violet record on a day with scattered clouds.
(2) ,, ,, ,, clear day, with some few clouds.
(3) Typical Ultra-violet record on a clear day.

Of the contributions prior to 1880, about 66% were Continental and 34% British, whilst mining, quarrying, anthracosis and metals received most consideration. Coal mining was almost exclusively studied by France and England, and the occurrence of anthracosis, melanosis or phthisis, discussed. The contributions on metal dust are likewise chiefly French and British, Discussions on the Diseases of Sheffield Grinders (Hall, 327), The Vital Statistics of Sheffield (G. C. Holland, 328), and Inhalation of Gritty and Metallic Particles (329) being the British contributions.

The connection between dust and tuberculosis seems to have been early recognized by Benoiston de Chateauneuf (330), writing "De l'influence de certaines professions sur le developpement de la Phtisie pulmonaire," and Lombard (331), "De l'influence de la profession sur la phtisie pulmonaire."

THE PHYSIOLOGICAL DUST DANGER AND ITS SCOPE.

As regards the physiological danger of dusts studied indirectly rather than directly, J. Tyndall, doubtless unfavourably impressed by dust normally inspired, and his discovery of the fact that aerial bacterial introduction and growth only accompanied atmospheric dust (*cf.* Dust in Experimental Sciences), was probably one of the first to inquire into the indirect significance. The underlying temperature differences governing disposition of dust in the lungs are linked with such observations as that of Tyndall (30) that a hot rod became surrounded by a region of warm dust-free air streaming upwards; Rayleigh (31) that a cold rod had a surrounding down current of dust-free air, the dust being deposited on the rod; Tolman (33) that tobacco smoke passed between concentric tubes at 50 degrees C. and 80 degrees C., respectively, quantitatively settled on the cooler; and Aitken (32) that solid particles present in flames are deposited on cold rather than hot surfaces.

Since the time of Tyndall, the whole subject has become of increasing importance until now, it is a question of pressing interest, involving widespread medical and scientific research; the close attention of many Government departments; the concern of huge industrial interests; the subject of much compensation provision; and a question of wide, and widening, public interest.

The particular dusts involved are, of course, all physiologically dangerous or undesirable. For the most part their

danger is due either to (*a*) chemico-physiological or (*b*) physico-physiological effects. Some, however, as above indicated, are chiefly dangerous, not so much in themselves as by acting as conveyors of dangerous dusts, e.g. bacteria. Almost all dusts of direct intrinsic danger are produced industrially, whilst those acting indirectly are incidental to everyday life. Again dust in general, e.g. the normal staubosphere content, may, either on account of its own proper action, or because it introduces suspended bacteria, assist the growth or continuation of diseases, e.g. tuberculosis, already existent in individuals, rather than itself initiating disease, as in the case of the dangerous industrial dusts.

The study of dusts as regards their harmful effects on human beings has hitherto been known by its correctly-derived name of pneumonoconiosis. But at the International Conference on Silicosis at Johannesburg, from August 13th to 27th, 1930, it was decided to adopt the now-recognized term—pneumoconiosis. Pneumoconiosis covers all work dealing with harmful physiological effects due to dusts in general, and lays special emphasis on silica dusts—or derivatives of silica. It, therefore, includes the incidence of dusts on all questions of general physiology and pathology, radiology and clinical pathology.

Many of the more practical aspects of this immense range are of such importance that they are set forth for public inspection in the Home Office Museum, Horseferry Road, Victoria, London, S.W. Here can be seen model exhaust ventilation systems; enlarged radiographs of silicotic and fibrotic lungs; models of normal and anthracotic lungs; realistic models of the effects of lead and chromium poisoning, anthrax, etc.; model equipment for respiration and hygiene; and many other appropriate items. In the House of Commons silicosis debate of March 29th, 1934, the cotton wool filtration of air for that chamber was put as a precedent for silicosis prevention in mines—stated to be the subject of negotiation between the Home Office and mineowners—and the discomfort aspect of respirators; the desirability of quicker compensation decisions; and the preliminary nature of present attacks on the problem were stressed.

Excluding articles on pneumoconiosis in medical, pathological, industrial medical works, and medical encyclopædias, the bibliography of pneumoconiosis is shown to cover the

following fields (332), whilst full accounts of silicosis up to the dates specified are given in two publications of E. L. Collis (333).

TABLE VI

Pneumoconiosis.	*General Pathology.*	*Experimental Research.*	*Clinic.*	*Industrial Pathology.*
General (93).	General (44).	General (28).	Pneumoconiosis (45).	Artificial abrasives and french mill stones (15).
	Dust cells (21).	Sampling and Control (15).	Anthracosis (11).	Alabaster (3).
	Pigment (17).	Anthracosis coal dust (16).	Silicosis—9 separate countries (80).	Asbestos (70).
	Anthracosis (61)	Silica (48).	Radiology (36).	Slate (12).
	Silicosis (13).			Barium (1).
	Dust and Tuberculosis (67).			Wood (3).
	Anthracosis and Tuberculosis (17).			Pottery (52).
	Silicosis and Tuberculosis (28).			Coal (5).
				Chromates (1).
				Cements (31).
				Cotton (8).
				Copper (2).

Industrial Pathology (*Concluded*).

MINES: General (9), Brown Coal (3), Coal—12 countries (102), Copper (6), Tin (1), Iron (6), Gold—4 countries (46), Lead (7), Lung Cancer (29), Zinc (2), Mother o' Pearl (1), Stones—quarries, stonecutters, etc. (43), Quartz (6), Basic Slags (18), Sulphur (15), Tobacco (6), Talc (5), Tunnelling (4), Miscellaneous dusts (12).	Flours (8). Iron (10). Smoke, Soot (6). Granite (19). Graphite (2). Sandstone (10). Marble (8). Metals (47).

N.B.—The figures in brackets are the number of references applicable to the subjects to which they are adjoined.

The above bibliographical field is practically exhaustive, covering publications up to December, 1931. Full references are given in "Pneumoconiosis" (332), from which the foregoing analysis is made, comprising the work of 837 authors, those who have made four or more contributions to one or other of the subjects being: E. Agasse-Lafont, C. Badham, A. Böhme, S. Bryson, E. L. Collis, L. Devoto, S. Doubrow, A. Feil, L. Ferrannini, L. U. Gardner, L. Greenburg, E. H. Greenhow, J. S. Haldane, E. R. Hayhurst, P. Heffernan, F. Heim de Balsac, G. Hoffman, Holtzmann, F. Ickert, L. G. Irvine, K. W. Jötten, A. Jousset, E. H. Kettlé, F. Koelsch, H. R. M. Landis, A. J. Lanza, A. Mavrogordato, E. L. Middleton, Th. Oliver, J. Peissachowitsch, A. Policard, V. Reichmann, O. Rostoski, A. E. Russell, E. Saupe, R. R. Sayers, F. W.

Simson, C. L. Sutherland, A. Sutherland Strachan, A. Thiele, W. Watkins-Pitchford.

SCOPE OF CONTRIBUTIONS AND RECENT FINDINGS.

The approximate total of 1,275 contributions to the subject up to December, 1931, includes approximately 373 published in Germany; 298 in the British Empire; 222 in France; 116 in Italy; 114 in U.S.A.; 17 in Russia; 11 in Holland; 6 in Spain; 5 in Sweden; 3 in South America; 2 each in Japan, Austria, Poland and Denmark; and 1 each in Czecho-Slovakia, and Latin (1556). The world-wide importance and urgency of these dust problems is thus evidenced.

Amongst the chief recent results and advances recorded are the conclusions of L. U. Gardner (499) that amongst marble, soft coal, carborundum, granite, asbestos, silica, and silicate dusts, only the two latter can cause significant reactions in lung connective tissues—suggesting, in general, that siliceous dusts cause reaction in so far as they establish direct contact with such tissue, the determining factor being the reaction of the phagocytes to various dusts; A general review of silicosis by E. L. Collis (500); A Home Office Report (501) on dust suppression methods in asbestos textile factories which indicates the advances made in exhaust ventilation, and includes agreements between employers and inspectors as to dust danger points; A symposium on the histo-pathology, pathological anatomy, and radiology of silicosis in South Africa by Simson, Strachan and Irvine (502); A review and discussion of anthracosis and tuberculosis in coal mines by M. Stassen (503). The findings of R. H. Pickard (511) from a wide survey, that cotton-card room dust consists chiefly of particles less than 10 microns, of about 90% organic matter, the fungus spores varying generally from 50 to over 90% aspergillus niger; and the work of Leon Prodan (529) showing that the effects of cadmium oxide fume and dust 83·5% less than 1 micron diameter—T. M. Legge (530) having previously shown 96% of such dust under 2 micron—and cadmium sulphide dust, is amongst other effects on animals, the production of generalized pneumonia and broncho-pneumonia.

THE HARMFUL EFFECTS OF VARIOUS INDUSTRIAL DUSTS.

The motto of Ramazzini—" Medici munus plebeios curantis est interrogare quae artes exerceant "—The duty of a doctor attending the common people is to enquire what trades they

practise—adorns the introduction to that extensive collective work, " Occupation and Health " (196). The actual practical details of incidental dust danger in industry, covering the detailed trades which are generalized in the preceding table are included therein. Of the several hundreds of industries considered, a very large proportion produce dangerous incidental dusts, e.g. there are about 25% in the first 80, and a representative summary of these is given in the following table :

TABLE VII

Industry.	*Dust Incidence*	*Effects.*
ABRASIVES.	Emery and carborundum dust, wedge-shaped particles. Norton Co., Mass., only 29 T.B. cases from 2,000 workers in 9 years. E. L. Collis found 26% bronchitis and emphysema in dusty operations. No T.B. Not dangerous dusts.	Possible silicosis. T.B. often accompanies sclerosis. Where prophylactic measures taken, bronchitis, emphysema.
AMBER.	Minute amber particles in working.	Particular case (Winter steiner, 1893) workers' cornea contained particles.
COFFEE, SUGAR, BANANA PLANTATIONS, EARTH TUNNELLING, DEEP MINING.	IN ALL—chiefly mines, where contamination by sweat, coal dust and mud on skin.	Ankylostomasis or Hookworm.
	MINING ONLY. Coal dust, silica, and rock and suppression dusts.	Anthracosis, occasionally silicosis and T.B.
HORN, HOOF, BONE PREPARATION.	Scraping and smoothing horn—previously sawn.	Anthrax possibility.
HARVESTING, AGRICULTURAL LABOURING.	Vegetable dusts acting as dangerous vehicles for parasitic infections.	Actinomycosis, Streptotricosis, parasitic infections.
ALABASTER QUARRYING.	Dust in long, badly-ventilated galleries.	Workers covered white dust like millers. Giglioli suggests T.B., Pieraccini and Mori only mucous membrane irritation.
ALUM.	In breaking alumite for roasting.	Should be avoided by breaking in closed ball mill.
ARSENIC.	In crushing, grinding, roasting, raking and sublimation. Airmen spreading lead arsenate anhydride—specially harmful.	Lung tumour—arsenic or arsenate of cobalt—(Schwarz, 1922) Schnaeberg miners. Lesion of nose septa.

TABLE VII (*Continued*).

Industry.	*Dust Incidence.*	*Effects.*
ARTIFICIAL FLOWERS.	" Dusting " leaves, flower centres, etc., with metal or colour, glass or crystal powders.	Domestic work. Bad ventilation. Possible T.B. lead poisoning and silicosis.
ARTISTS (various).	Dramatic artists.	Illness due to dust.
	Sculptors.	Respiratory troubles and irritation of nose and eye mucous membrane.
BAKELITE.	Dust smelling of phenic acid, in turning and polishing.	Marked nervous trouble. (Dutch Medical Inspectorate, 1926.)
BARK MILLS.	Powdering tanning dust.	Upper respiratory passage troubles. (Special regulations—Gt. Brit., France, Spain.)
BREWING.	Considerable dust due to barley manipulation. Also turning grain in oast house.	Upper respiratory passage troubles.
BROOM MANUFACTURE.	Dust due to beating. Sorghum plant to remove seeds, liberating much dust gathered in summer.	Upper respiratory passage troubles.
BUTTON MANUFACTURE.	Fine, white, pearl dust, ivory dust, etc., prolific (covering objects) due to sawing, cutting, hole-drilling, polishing, etc.	Serious respiratory effects effects. Ivory dusts very harmful. Pearl dust—dyspeptic and catarrhal affection of respiratory passages. Toxicity from colouring matter.

Certain fumes may be included amongst these dangerous dusts. Inhalation of some of particle size 0·2 micron to 1·0 micron, e.g. oxides of zinc, copper, cadmium, magnesium, mercury, and manganese dioxide produce febrile conditions. Thus, amongst skimmers and pourers of molten brass, there is some indication of a high tubercular rate, though the groups examined also included buffers, polishers, etc., suffering from dust incidence, according to " Occupation and Health " (196).

The above little-known incidences serve to show the insidious physiological scope of dusts. The dust hazards in flour milling, bakeries, bronzing or bronze manufacture, building trades, asbestos industries, and basic slag industries are probably better known. Thus, the asbestosis of the asbestos industries is now attracting much study, its effects being roughly analogous to silicosis, though it exhibits definite characteristics such as the " peculiar bodies," and the most dangerous operations

are spinning and weaving. Fibrosis and tuberculosis often result, and the relation to the latter has been shown in an annual report (334). A Canadian investigation in 1911 showed that although respiratory diseases, particularly tuberculosis, were still very frequent, great improvement had been reaped from good ventilation.

Probably the outstanding industrial case of widespread dangerous dust incidence in a single manufacture is that of the basic slag industry. It seems worthy of special consideration. The workers deleteriously affected are (1) those in all branches of its manufacture, (2) transportation personnel, e.g. railway or dock workers, (3) agricultural labourers. The basic (Thomas) slag is pulverized in ball mills, further ground and sieved, and either stored in bags or wooden silos. For maximum manure efficiency the slag must be very fine. In discharging the slag from furnaces, it may be very dusty, as it disintegrates under the action of carbon dioxide and moisture. It may be noted, in passing, that Swingle (451) has also studied chemical changes in storage of sulphur, lead arsenate, and lime dusts. Pulverizing, sieving and bagging the slag are also very dusty, in spite of enclosed mills, exhaust ventilation, etc., and if stored in bags, the fine powder rots the bags, which burst. Empty sacks—which must be de-dusted to protect sack repairers—must be beaten, and create dust Even when they are of close texture, the fine dust escapes the bags, and transport workers have complained of the harmful effects. Workmen in the bagging department are often covered with fine dust. Agricultural workers, owing to wind effects, and their own essential work on the material, produce for themselves as dangerous conditions as machinery and manufacture create for workmen. Part of these widespread effects can be eradicated by the modern Mathesius process which pulverizes slag—without crushing or grinding—by two or three hours' treatment under ten to twelve atmospheres pressure in a steam boiler. Basic slag is also used for making " silicate of cotton " (" mineral cotton "), consisting of filaments due to violent pulverization of the slag in contact with a steam jet. This material also produces dangerous dusts in packing.

The controversy regarding the action of the sharp slag particles seems now to have been decided in favour of a physicochemical explanation—a view supported by Villaret, Rambousek, and Koelsch. According to " Occupation and Health "

(196), from which the above information comes, a German inquiry by the Reich Health Office some years ago showed considerable seriously developed respiratory diseases, whilst Weyl found over the years 1903–1913 an average of 41·5% of respiratory disease, and 2·2% deaths from pneumonia, over 9,984 employees. In Great Britain, a committee (335) considered basic slag dust. Serious pneumonic epidemics were thought due thereto in 1888, 1893, and 1900, though the Ballard enquiry into Middlesborough basic slag grinding concluded that pneumonic epidemic was not caused by slag dust which, however, was a predisposing factor. E. L. Collis showed the existence of bronchitis, slag workers' cough, and pneumo-silicosis in "mineral cotton" factories, and that persisting workers were seriously attacked. Pneumonic epidemics at Nantes were also reported by Ollive, 1888, and Monnier and Gautret, 1921 and 1924, and of asthma in Dutch workers in 1923. The effect on women workers during the war (1914–1918) was greater than on men, particularly regarding influenza.

DISEASES PRODUCED BY DUST RESPIRATION.

Dusts may produce disease either by external or internal incidence, but perhaps the chief distinction is between chemical and physical (or physico-chemical) operation. Thus chromium and lead poisoning, or anthrax, are chemical, whereas silicosis, anthracosis, phthisis, asbestosis, tuberculosis, are physically (or physico-chemically) produced. Since the chemical poisoning may be caused by solutions as well as dust, whilst silicosis, etc., are always caused by dusts, these latter will be chiefly considered. Of these various diseases, silicosis has widest application and is most dangerous, for tuberculosis is, in this connection, a dependent disease, being generally preceded by silicosis when due to dust inspiration. Silicosis may have particular trade names, e.g. grinders' rot or chalicosis when due to stone working or cutlery manufacture. Similarly, siderosis is the trade name for metallic (iron) dust disease.

According to Black's Medical Dictionary, pneumoconiosis "is the general name applied to a chronic form of inflammation of the lungs which is liable to affect workmen who constantly inhale irritating particles at work. The disease produced may be of the nature of chronic interstitial pneumonia, but is very liable to result in the true phthisis from the engrafting of the

tubercle bacillus upon the diseased lung." This definition includes that of silicosis, which is "a form of chronic interstitial pneumonia," and shows the true nature of phthisis. The particles which cause systematic damage act over considerable periods, and are of 0·4 micron to 6 micron, or over, diameter—P. Drinker (196)—though it may be more explicitly supposed that those up to 5 microns are dangerous, with an average of alveoli entrants of 2 micron, and a most dangerous diameter of 1 micron. They are generally of free crystalline silica, and the degree of silicosis probability, it is now thought, can be estimated from the concentration of dispersions, period of exposure, and percentage of free silica in dust inhaled. Absence of silica does not imply absence of pneumoconiosis, and it is questionable whether silicates such as cement and asbestos (in absence of free silica) cause fibrosis. And although such substances as quartz and granite seem much more harmful than free silica with silicates, it is now considered that fibrosis is not caused by hardness or sharpness of particles.

According to Collis and Greenwood (336), in general, dusts are the more dangerous the less they are like the human body or its composing elements. Hence, whilst animal dusts are less injurious than others, vegetable fibre husk tends to a typical form of asthma associated with bronchitis. This may be expected to result from continual inhalation of such dusts as, e.g. those from cotton ginning or carding, which, in addition to much fine dust and fibrous material, contains sharp, hard, spicules of pod in considerable amount. Further particulars concerning the nature of dust in cotton card rooms is supplied by the British Cotton Industry Research Association (452).

Since, for fatal development of silicosis, 10 to 25 years may be required, and diseases due to asbestos and cement are of relatively new observation, it is still rather soon to generalize. This is emphasized because the X-ray method of diagnosis recognizing three stages of pneumoconiosis is also relatively new. It has been found—Drinker (196)—that by injecting colloidal silica intravenously, toxicity and fibrosis are produced, which seems to suggest the harmful action of silica particles as chemical, and studies of the effect of subcutaneous introduction of crystalline silica mine dust are being performed. Strides towards determining the threshold value of silica dust exposure are being made by rapid dust determination experiments on men and animals, with considerable accuracy. Particle

surface effects govern the removal of dust particles from the alveoli, which can be understood in light of the fact that positive dusts (e.g. silica) are preferentially water-wetted. Thus, in experimentally phagocytosing different dusts (*in vitro*), carbon is selected thrice as readily as quartz. On the other hand, evaporation of moisture from lung surfaces tends to prevent initial deposit of dust particles.

Anthracosis is shown by definition to be almost lacking in harmful effect, though the lungs and bronchial glands change in colour from greyish-pink to jet black. It is now much less common than formerly, owing to better ventilation. Normal, uncontaminated lungs being greyish-pink, and the lungs of all city dwellers becoming darkened owing to continued dust and smoke breathing, all such individuals may be regarded as suffering from mild anthracosis.

How Inhaled Dusts Operate in Disease Production.

Whether dust particles which are inhaled are arrested in the bronchii, or pass further into the lungs to the alveoli, chiefly depends on their particle size. The etiology (Encyclopædia Medica) of dust diseases seems to vary with the vegetable, animal, or inorganic origin of the dust. Thus, with vegetable dusts, whilst most are trapped in nostril-entrance hairs, in nasal mucous-membrane moisture, and ciliated epithelia of the main passage, excess particles pass to the larynx and trachea, and are expectorated after stimulating mucous secretion, e.g. "black spit" of miners—coal dust particles. The basement membrane is a barrier, but through irritation, bronchitis, bronchial catarrh and emphysema may facilitate passage to the alveoli, where those not absorbed pass between the cells, and, entering the lymph channels, move in the lymph stream, and are deposited in the peribronchial and perivascular tissues. Gradually the interlobular septa and pleura are reached, and the bronchial, retrobronchial and tracheal glands attacked. Blackening results, and lymphatic circulation may be impeded with necrosis and sloughing of lung tissue. This generally takes a long period to complete. Other dusts such as flour, cotton, wood and other grains, produce similar effects, but without pigmentation. In the case of animal dusts, e.g. silk, horn, ivory, wool, etc., particle formation is generally less, and the upper air passages only are affected. Inorganic dusts which include quartz, silica, other stone, and metal dusts,

on reaching the alveoli and entering the lung parenchyma, a hyperplasia of connective tissues occurs as reactionary fibrosis or cirrhosis. This extends and becomes associated with pleural thickening, adhesions, and perhaps bronchiectasis. But the pathological changes due to all dust inhalation are partly the same, including chronic bronchitis, peribronchitis, and more or less intense, widespread pigmentation. Also bronchial glands become enlarged and pleura involved. Cough—becoming more stubborn—and dyspnoea (which may be due to bronchitis, fibrosis, emphysema, etc.) are usual symptoms. Expectoration contains dust particles, cyanosis may be pronounced, and tuberculosis ensue.

Phthisis is a distinct disease, a secondary infection consequent on fibrosis or silicosis. Its correct name is tubercular silicosis, and it belongs to the group named by J. Brownlee (346) " middle-age " type.

Particles of sufficient size to be ejected by the ciliated epithelium are not generally dangerous, not giving rise to serious lung diseases, though doubtless, continued bronchial deposition may cause irritation, and perhaps bronchial trouble. The dangerous average size of about 2 micron diameter is, of course, very important. Industrially, much fine dust is formed of smaller dimension, and all such must be regarded as potentially dangerous. J. S. Haldane (337) states that dust danger in mining had previously been associated with work in stone (rather than coal), and that even extremely small amounts of minute particles of certain dusts are dangerous, though not all kinds of insoluble dusts. Extremely large amounts of any dusts would be dangerous for either workers or citizens, but *coal* miners suffer little from phthisis, because dust is eliminated about the same rate as it is deposited. This conclusion may be drawn from experiments on pit pony lungs by F. Haynes (338). The limit for dust concentration with certain dusts before danger ensues is, therefore, a high one. But on the other hand, dusts regarded by experts as " inert " often, finally, attack the mucous membrane of nose, conjunctivæ, teeth, skin, digestive tract, or upper and lower respiratory passages in a harmful and subtle manner. Haynes (339) has further shown that the most deadly dust to animals (guinea pigs) was precipitated silica, whilst less dangerous ones—though all producing fibrosis—arranged in order of toxicity, were flint, slate, aluminium hydroxide, precipitated chalk, magnesium

carbonate, and carborundum. Calcspar and emery would cause fibrosis, if appreciably inhaled. He has also shown that coke dust failed to produce fibrosis, and that shale (washed) appears to cause fibrosis more readily than shale (unwashed). The distinction between the relatively innocuous dusts, e.g. flour dust, which seems only to affect upper respiratory passages —the composition of grain dust is studied by Baltrusch (448) —and typically dangerous dusts is that, whereas dusts are in general retained to the extent of 40% to 60% of the amount inhaled, alveolar absorption is greater the "deeper" the breathing. Drinker, Thomson, and Finn (449) found the percentage retentions of zinc oxide fume and marble dust of size 0·15 micron to 6 micron to be 55, plus or minus 9·4, i.e. from 45·6 to 64·4. Furthermore, particles of 0·5 micron or less are always present in expired or alveolar air, and since the elimination process breaks down with dangerous dusts, collection in the lungs—engendering infection by the tubercle bacillus—proceeds until serious results ensue.

There is still controversy as to the nature of the action of the deposited dust, some considering it to be physico-physiological—the particles creating nodules with phagocytes which extend to form fibrous tissue throttling lung action—others that the action is chemico-physiological, e.g. between a potassium aluminium silicate—sericite—and lung tissue, and with this latter idea in view, work to develop a microchemical method for analyzing lung sputum, mine dust, etc., samples has been recently put in hand (340). Precipitated silica inhaled in large amount has a general toxic effect—suggesting chemical action—but, on the other hand, Lorrain Smith has noted that pure oxygen acts as an irritant of the alveolar epithelium as dust does with isolated cells, and Haynes (341) is studying this effect along with the effects due to intratracheal injection of dusts. W. E. Gye and E. H. Kettle (343) consider that the lower size limit of dangerous silica dust, being indeterminate, such fine material can have no mechanical ill effect, whilst Gye, Purdy and Kettle consider that the silica "ion" is toxic and a cell poisoner. P. Heffernan (344) concludes that harmful effects of silica appear to be due to its powerful colloidal potentialities, rather than to toxicity of the silica "ion." J. S. Haldane (337) considers certain dusts, possibly hæmatite, are chemically prejudicial, whilst others such as flax dust, tend to bronchitis. Dust having an essenti-

ally chemical effect, may also operate physically. Thus, the physical properties of arsenical dust, studied by Streeter (453), may come into play. Whilst it has been recently decided that dry drilling in soft haematite does not produce dust in dangerous amount, the Health Advisory Committee of the Mines Department now recommend the discontinuance of dry drilling.

Preventive Studies and Methods against Inhaled Dust Diseases.

The problem of preventing pulmonary dust diseases in all the industries where they are likely to occur is a huge one. But, qualitatively, it is a problem of simple definition. It is now well established that particle dimension is the deciding factor regarding danger. For the average size of particles penetrating to the alveoli is 2 micron, and the really dangerous complement, 1 micron diameter. Particles greater than, say, 5 or 6 micron, will be dealt with by the upper passages and emitted as quickly as inhaled. No matter, therefore, what quantity of dust is produced less than 5 or 6 micron diameter, if prevention of inhalation can be secured, serious deep-seated dust disease will be eliminated. Collis and Greenwood (336) state that bronchitis is the chief of pneumonoconioses following on excess inhalation of every form of insoluble and non-colloidal dust. Pneumonia may follow on inhalation of such dusts. The difficulties in the way of ultimate elimination are chiefly threefold, viz.:

(*a*) The methods and machinery aiming at dangerous dust removal have been in practical use before the determination of dangerous dust dimensions.

(*b*) The real difficulty of discovering material or materials to arrest particles less than 2 micron diameter.

(*c*) The real difficulty of overcoming the prejudice (and largely the discomfort) to wearing respirators which could arrest before inhalation, the dangerous fine particles.

Without doubt, all these difficulties, particularly the latter two, will have to be overcome in the efforts of the Department of Scientific and Industrial Research to develop a really effective type of dust respirator. It was chiefly the difficulty (*c*) above, allied to its belief that an appreciable amount of dust-contaminated air is liable to pass between respirator and face, which led to expert findings against the use of respirators (347), except in

the case of dangerous dusts, etc., when a cotton wool pad is recommended. Doubtless, also, the consequent satisfaction with cotton wool pads has made necessary the discovery of a new material if a really efficient respirator is ever to be used. At the same time the committee (347) studied thoroughly the efficient use of ventilation, particularly in such industries and processes as: metal polishing, enclosed emery wheels, other grinding, textile dusts, bone sawing and finishing, white lead dust production, towing berths in earthenware works, pottery dust (flat knocking), sanitary ware, grinding glazed bricks, linotype machines, rag sorting, and paper milling.

Whilst the ideal objective is to prevent all dangerous particles less than 5 to 6 micron diameter from entering the lungs, there is a certain latitude allowable, i.e. some such particles may be inhaled over long periods before actual damage ensues. This period varies from person to person, owing to physical initial condition, from dust to dust, and with other factors, so that no definite threshold value is yet definitely determined. For what, perhaps, is the most extensively-produced industrial fume, viz. zinc oxide—whose inhalation gives rise to "fume fever"—threshold doses have been considered by Drinker, Thomson and Finn (349), and in this connection Gottfried Seiler, 1928, found that the finer the dust the less the difference in percentage of sedimentation at various heights, and that, for particles of 10 to 15 micron diameter, the ratio of dust remaining suspended to that deposited was 1 : 3·6. These results apply to still air, whilst that of workrooms, factories, etc., is not, generally, quiescent. As recent American research has shown that particles greater than 10 micron diameter do not penetrate the alveoli (*cf.* previous figures) if, as particles become less than 10 micron diameter the above ratio becomes less, then alveoli penetration will become more pronounced with decreasing particle size. But, no matter how slight the rate of entry, the effects are cumulative, and rate of accumulation will be varied, as above. The undesirable end is, therefore, sooner or later inevitable, once the threshold value is overstepped. Total exclusion of dust is, therefore, the desirable aim. Even 26 years after completely leaving the industry, a female worker who had only inhaled asbestos dust for six months all told died of pulmonary asbestosis.

According to Haldane (337), miners' phthisis was first observed in coal miners about two to three years ago in Somer-

set and South Wales, due to sandstone drilling in stone drifts. In this connection, it must be noticed that several Somerset miners who were X-rayed for the 1925 investigation for supposed silicosis have since died. Whilst the Health Advisory Committee are closely concerned with dust diseases in coal mines, and the Mines Department has arranged with the Medical Research Council for further medical inquiry by the Research Committee on Industrial Pulmonary Disease to determine the effect of anthracite dust (excluding other dusts) on health by studying surface (e.g. screening plant) mine workers, and the physical and chemical study of atmospheric dusts occurring in various industries, a special study of silicosis in coal mines is being made by the Executive Board of Mining Research at Birmingham University, financed by the British Colliery Owners' Research Association. The latter body is also carrying out research on such problems as spontaneous combustion and dangerous underground atmospheres. Their latest silicosis research has been the analysis of "hard-heading" rocks, of stone dusting materials, and of free silica determination methods. X-ray examination for silica has been found inadequate, and the "rational analysis" method modified to employ samples of 0·15 gm. instead of 5·0 gm. of dust. Some collieries appear to be using "stone" dust containing over 35% free silica, and it is suggested that collieries keep records of silica in air and in borings in connection with silicosis compensation. The use of dust traps is found in South Wales, Somerset, North Staffordshire and Channock Chase to leave a large amount of dust in the air, and collaboration is being set up to render "dust trapping" more effective by adding chemicals to water for wet drilling. Different methods of dust prevention are also being tested at the Mining Research Laboratory.

The dust trap of P. S. Hay (337) has been introduced on the basis provided by the Miners' Phthisis Prevention Committee of the Union of South Africa (342) that mine atmospheres are "*safe*" *if dust concentration is less than 300 particles per c.c.*, and that, since fine particles are most important, those over 12 micron diameter need hardly be considered. Almost thrice the number of these dust traps were in use in 1930 as in 1929, and a further 200 were added in 1932. A new type of dust trap has also been approved in 1932, and a further type (making three) has been improved. A foam dust-allaying

appliance has also come into use, which takes less water to entrain dust than ordinary water spraying. In America, the Kelley dust trap has been developed for rock drilling, and its efficiency and operation are discussed by Hatch, Warren, Kelley and Fehnel (504). The Hay dust trap (337), from the experiments recorded, is shown to reduce the number of particles whilst drilling from the order of over 2,000 per c.c. to between 163 to 332 per c.c., the lower size limit of the particles being 2 micron. Undoubtedly great effort will be made to obtain a material which will carry this lower limit much further, so as to cover the most dangerous-sized particle of 1 micron, or less. For the 2 micron limit seems to mean that whilst probably, in common with water spraying and exhaust ventilation (where applicable), the dust trap is very beneficial in keeping back the bulk of the dust formed, thus preventing the entry of much to the lungs, it probably allows the most dangerous particles to be still inhaled by the operators. Whilst flocculation is assisted by atomised water jets or steam—with dusts which can be wet by water—complete dust removal is never so achieved, and the sparser the dispersion, the less effective the spraying. Whilst serious dust disease due to coal mining is relatively slight and of only recent notification—though King Edward VII Welsh National Memorial Association (18th annual report) shows the characteristic radiological appearance of coal miners' lungs to resemble those of silicotic cases, and a comparatively high bronchitis mortality amongst anthracite miners—gold mining, particularly as practised on the South African Rand, is liable to be very productive of silicosis, owing to the metal being found in quartz, and the often-ensuing tuberculosis is especially prevalent with native labour, although the fact that the native labourer is, temperamentally, a temporary one—taking leave to disburse periodical earnings—may, whilst somewhat mitigating its effects, cause them to be less localised. Full particulars of the onset and effects of silicosis, of strongly organized examination, notification, and compensation at great expense, to keep the disease in check, can be found in Records of the International Conference on Silicosis held at Johannesburg, August 13th to 27th, 1930 (International Labour Office—Studies and Reports—Series F (Industrial Hygiene) No. 13, Geneva, 1930). At this conference, the effects of mixed dusts discussions led to tentative conclusions thereon ;

the effects of concentration of dusts was studied, and methods of estimating silicosis, and the most recent advances were discussed.

The very remarkable gulf between the practical immunity of coal miners from, and the great susceptibility of gold miners to, silicosis or similar dust disease, has doubtless stimulated attempts to advance explanations. Thus J. S. Haldane (345) advances the findings of Mavrogordato, that coal dust has a beneficial effect in nullifying the dangerous effect of flint dust. In the case of lead miners, the tendency to silicosis danger seems to be affected to some extent by the locality of the mines. Thus, in the district of Blanchland in Northumberland, where lead mines have been worked for centuries (Letters Patent of March 23rd, 1475, granted mine of Shyldeyn by Edward IV) old miners suffering from silicosis may be found, though miners having worked in other mines in the neighbourhood do not seem to have suffered. All the veins carry fluorite, but at Shildon (Northumberland) they also carry a large amount of chalcedony with quartz crystals, according to S. Smith and R. G. Carruthers (348).

Methods and Machinery (*a*).—The methods and machinery vary with their convenience in particular industries, and the tradition of the industry. Thus, in instrument grinding—of which Sheffield may be considered the cradle—the original "dry grinding" which gave rise to such a proportion of "grinders' rot" that hardly any grinder lived to a greater age than forty, and the use of millstone grit (sandstone) wheels which had to be "raced" with a tremendous preliminary dust output, was replaced by "wet grinding" with sandstone wheels, and, still more recently, emery and carborundum grinding wheels which produce less, and less dangerous, dust. The most modern improvement also now found in many grinding shops and sheds is exhaust ventilation, individual hoods often almost completely covering the wheel. The risks are thus apparently, and doubtless really, greatly reduced, but numerous cases occur, varying from industry to industry dependent on the nature and fineness of the product, where up-to-date exhaust ventilation is only partially effective. Thus, many modern boot repairing firms employ advanced machinery with exhaust ventilation, but thick layers of leather dust can often be seen on all adjoining objects. Gundermann (1928) drew attention to the use of old tools and inefficient dust

exhaust systems causing quantities of dust in steel ball bearing polishing rooms, and in the wood-working industry. In coal mining, "dust traps" have been introduced, and respirators are worn by many workers in many industries, e.g. some operations in flour milling, though many use exhaust ventilation, a large firm in the North, in common with others, exhausting the dust through the roof, in a manner illustrated by W. E. Gibbs (350).

More attention is also now paid to general ventilation and workshop space, both voluntarily, and under regulation. The Mines Department has taken up with the slate mining and quarrying industry the question of certain workers who may, after a prolonged period, suffer dust disease, and such firms have now agreed to dampen dressing shed floors, collect and remove debris systematically, and deal with dust made by cutting and dressing machines—a remedy which is proving effective.

One of the most misleading and dangerous characteristics of dust of dangerous size is its relative invisibility (in small volume). This has tended to create a false sense of security, for all save the scientifically trained regard visibility as the ultimate test of presence. The problem, therefore, resolves itself into that of (*b*)—page 242.

Suitable Filtering Materials and Discomfort Aspect (*b*) *and* (*c*).—A water spray on to a grinding wheel gives a very obvious and apparent withdrawal of dust. But a water spray is, nevertheless, practically powerless to arrest the dangerous particles less than 5 micron—so that it is merely cleaner, and cannot, most probably, prevent serious dust danger. Whether exhaust ventilation shall be effective depends rather upon a balance of factors in particular cases, e.g. the strength of suction, the respective distances of worker's mouth and exhaust duct from seat of dust production. Exhaust ventilation will, probably, discourage ordinary ventilation, so that dangerous dust escaping to the room will accumulate, to be stirred up for breathing by moving objects and persons.

Whilst thick layers of dust may be often seen settled on machinery and other objects in workrooms where exhaust ventilation is employed, since it is almost certain to extract some of the very fine dangerous particles, it may be regarded as more effective than water-spray and filtration methods, whether as respirators or impersonal filtering instruments such

as the dust trap, for, until very recently, no very effective filtering material has been discovered for inclusion in such generally available instruments as respirators.

Excluding the discovery of a perfect filtering material, the solution of the problem is likely to be found along the lines of combined exhaust ventilation, and elimination of implements which produce dangerous dusts (e.g. sandstone grinding wheels), though, obviously, this cannot apply to industries, e.g. silica brick manufacture, where the dust-forming material is sought for its own sake. Neither can industries which are followed in the open, e.g. ganister mining, so easily be made the subject of exhaust ventilation. In such cases, therefore, the conditions necessitate the provision of respirators as the only suitable preventive (until and unless substitution completely displaces man-power), despite the fact that the factor of personal prejudice to wearing respirators enters into consideration—a factor which, in cases where exhaust ventilation or replacement of implements can be applied, will discourage respiration advances. The objection advanced against respirators in general by Collis and Greenwood (336) is that the dead space in front of the nose and mouth retains expired air, causing deeper breathing to eliminate the normal amount of carbon dioxide, and this objection seems to justify the wearing of soft pads strapped over the mouth and nose. A suggestion of the Departmental Commission (347).

Fieldner (444) has discussed the use and limit of respirators in industry ; Katz (445) and others have tested the characteristics of dust respirators, and Lockhard (446) has explained a face mask for protection against industrial dusts.

But the " discomfort " aspect of respirators is being overcome by the new ability to mould highly porous rubber into very soft and appropriate shapes for face wearing. A light, comfortable, highly efficient respirator with a probable filtering efficiency of up to 85% at a breathing resistance of but 0·5 ins. water gauge may shortly be on the market as a result of joint Home Office, Mines Department, and Department of Scientific and Industrial Research efforts. In the report of the latter Department for 1932 to 1933, it is stated that such an industrial dust mask has been tested, satisfactory results being obtained in mines, quarries and silica and asbestos works. It may be supposed that a material which will arrest particles of less than 2 micron diameter, thus preventing dangerous dust

disease, is incorporated in such a new dust mask. At all events, that is of the highest desirability.

In connection with the production of the industrial dust respirator above referred to, S. C. Blacktin carried out research into the discovery of a material from September, 1930, to March, 1932, which would arrest particles of less than 2 micron diameter, thus preventing dangerous dust disease. The essential characteristics of such a material are (1) that it should arrest a very large proportion—the higher the percentage the better—of particles less than 2 micron diameter, with (2) minimum resistance to breathing for maximum period, at minimum weight, with (3) minimum tendency to absorb moisture from air before or after respiration. Numerous materials, e.g. fibres, textiles, cereals, unprepared plant products, etc., were experimented with, the efficiency of different suitable areas under varying conditions being studied. Their filtering efficiencies were compared in terms of particles of diameter about 0·16 micron.

Before this work was undertaken, the most generally used material in industry had been cotton wool pads. A large number of different styles of dust respirator was studied by the U.S. Bureau of Mines, but even the best had but an efficiency of 50%. It was found by Blacktin that a certain tree fibre possessed characteristics which compared with those of cotton wool as follows :

TABLE VIII

COMPARING RESPIRATOR CHARACTERISTICS OF VARIOUS MATERIALS.

	Equal Wt. 3 gm. each. Area 60 sq. cm. Depth 2·5 cm. Vol. 150 c.c.		Equal Resis. 0·3 in. w.g. Area 60 sq. cm. Depth 1·25 cm. Vol. 75 c.c.		Equal Protection = 75% Area 60 sq. cm. Depth 1·25 cm. Vol. 75 c.c.	
Substance.	*Protec.*	*Resis.*	*Protec.*	*Weight.*	*Resis.*	*Weight.*
(*a*) Tree fibre	97%	1·0 in. w.g.	77%	1·0 gm.	0·3 in. w.g.	1·0 gm.
(*b*) Kapok	60%	0·3 ,,	60%	2·0 ,,	0·9 ,,	3·5 ,,
(*c*) Cotton wool	32%	0·1 ,,	58%	5·0 ,,	1·1 ,,	7·0 ,,

Recently considerable agitation and controversy has arisen concerning compensation in this country for silicosis and other respiratory diseases contracted in steel and other industries, with a view to getting them scheduled as diseases under the Workmen's Compensation Act, rather than being, as at present, contained in statutory rules and orders. It has been stated

that numerous workers were totally incapacitated by silicosis without being able to claim compensation; that 35% of a Grinders' Union were either affected by, or died from, silicosis, and that—over a period of 12 years—47% of Sheffield cutlers have died from respiratory disease other than silicosis. About 80% of the workers in such trades are, therefore, affected deleteriously in health by their work. Similar dangers are experienced amongst pottery workers.

Agitation amongst the miners of South Wales has also recently led to the request for a deputation to be received by the Home Secretary from the Miners' Federation, on the same account. For it appears that steam and anthracite coal mining in South Wales is dustier than other coal mining, and A. H. Cox, who has prosecuted an inquiry for the South Wales Miners' Federation (" Colliery Guardian," October 27th, 1933), concludes that dry and dusty mines are dangerous, irrespective of silica rocks so classified, and that silicosis is more prevalent in South Wales, and particularly in the anthracite area, than in any other home coalfield. The law seems to allow drilling in rock containing up to 80% silica. Acute cases are also stated to occur in Somerset and the North and Midlands, and the Various Industries (Silicosis) Scheme, 1931, is sought to have its provisions extended to include compensation for all underground workers. Cox suggests that the excessive dustiness may be a pre-disposing cause of silicosis, and that medical evidence to that effect may gradually accumulate. This, however, seems to be opposed to some views, which suggest that simultaneous coal dust breathing inhibits the effects of silica dust. Thus J. S. Haldane (345) refers to Mavrogordato's experiments showing that, on adding coal dust to flint dust, results indicate that all flint dust is gradually eliminated within a moderate time.

Dust hazards in some industries are dealt with by Miller and Smyth (63), Smyth (64), Wegmann (65), and Areus (66).

W. R. Jones (533) states the South African (Witwatersrand) silicosis cost for compensation for 1932 was £1,200,000. He considers prevention methods in force there. Differing from the conclusions of the International Congress on Silicosis, 1930, he considers substances like sericite, sillimanite, tremolite, rather than quartz or uncombined silica, a more sure cause of silicosis; also discussing the minerals which cause silicosis at the 1933 meeting of the British Association.

DANGEROUS INCIDENTAL DUSTS NOT INDUSTRIALLY PRODUCED.

Fortunately, most of the bacteria moving about in the air are non-pathogenic, and investigations have not supported the view that the air is the medium of spreading pathogenic organisms.

The many micro-organisms of the air include, in addition to moulds, micrococci as the most frequent bacteria, the chromogenic forms, e.g. cinnabareus, aurantiacus, sarcina lutea, and s. rosea predominating, and of bacilli subtilis and mesentericus (Encyclopædia Medica). Miguel, who made observations on the outskirts of Paris, and in the city, seems to have made a most systematic determination of moulds and bacteria in the atmosphere finding 145 to 245 moulds, and 170 to 345 bacteria, in the environs, and 1,345 to 2,500 moulds, and 4,305 to 9,843 bacteria, in the city, per hundred litres of air, varying with the season of the year. Carnelley, Haldane and Anderson (351) found in Dundee:

	Cleaner.	Average.	Dirtier.
In two-roomed dwellings ..	10	22	69 micro-organisms per litre of air.
In one-roomed dwellings ..	18	45	93 micro-organisms per litre of air.

and, in outside air, 0·8 micro-organisms per litre. The increase was mainly due, not to moulds, but bacteria. The proportion of moulds to bacteria was 1 : 3 in outside air; 1 : 20 in two-roomed dwellings; 1 : 48 in one-roomed dwellings. An average of 39 analyses of factory air gave 10·2 micro-organisms per litre, 2·2 being moulds, 8·0 bacteria—chiefly in lighter trades. Whilst no definite relationship has been established between epidemic diseases and outbreaks, and the numbers of micro-organisms, Miguel in 1893 noticed a sudden increase in zymotic mortality following by several weeks a sudden increase in micro-organisms, on four different occasions. Germano considers that dust-borne typhoid fever cannot spread up to a distance of several yards. This is probably because pathogenic organisms, which cannot live without moisture, can find sufficient only on large dust particles, which retain sufficient, but are not carried far on account of their size. But since the bacillus Löffler is fully virulent when quite dry, diptheria can travel greater distances (Encyclopædia Medica). Light, however, has a destructive effect on the carrying virulency of

bacilli, but juxtaposed to this is the conclusion of Carnelly and Haldane (351), from their work in London and Dundee, that sewer air is in very much better condition than the air of ventilated schoolrooms as regards organic matter and micro-organisms. Nevertheless, it is the increased light exposure out of doors, allied to the freer air and oxygen movement and more varying temperature effects, which makes the bacterial effect of outdoor air tremendously less significant than that of indoor air.

Unlike industrial dusts, which gain their dangerous significance from dispersion in air, microbic dangerous dusts gain theirs from settlement and multiplication in dark corners of all kinds, covered or uncovered. Thus, e.g. where ventilating air is required to be freshened without losing its warmth, as in conditioning for large buildings, the growth of moulds and pathogenic bacteria is facilitated.

Whilst the Childrens' Act prevented young children from crawling on public house floors, from which one in three samples on the average contained living and virulent tubercle bacilli (352), they may still often be gathered from house floors, deposited there from street-walking footwear, the brushing of clothing, etc.—the origin of much of which is too unsavoury to dwell upon. There can be little doubt that the most efficient method of cleansing or conditioning normal air is that of electrostatic precipitation, as bacteria are not merely removed, but killed, by this process. For further particulars, Tolman, Reyerson and others (67), W. D. Bancroft (68), D. Prince (517), Proctor (518), Hunt (519), and Prudden (520) should be consulted.

The possibility of much-needed subsequent progress in stamping out these quite common and general breeding grounds for dangerous bacteria—which are particularly vicious in that they act selectively on the successive generation owing to their nearer proximity to the more sensitive organisms of children—was inaugurated by the valuable discovery of John Tyndall that dust and microbic disease are co-existent. One of the greatest consequent discoveries which have benefitted mankind has been that of the spread of tuberculosis from a sufferer via expectoration and consequent dust, to a further victim, and the resulting open air tuberculosis cure invented in Germany.

The influence of various kinds of dusts on the health of man, animals and plants is discussed by E. Natho (447).

Dust and Natural Ultra-Violet Radiation.

The beneficence of ultra-violet radiation is becoming more and more obvious and generally appreciated, whether from the viewpoint of general health maintenance, or from that of the prevention of definite rachitic disease due to vitamin starvation. The Sunlight League in Great Britain keenly interests itself in what its chairman—C. W. Saleeby—calls the "diseases of darkness," which are assisted by obscuration of natural ultra-violet radiation due to atmospheric pollution. Its tonic properties have also been recognized in the increasing therapeutic use of artificially produced ultra-violet radiation, and analysis of substances by ultra-violet rays (natural as well as artificial) has come to be of industrial importance. In any use, where the source is sun, dust will have a huge inhibitory effect, and a small, perhaps insignificant one, where the source is artificial. The hygienic effects of the ultra-violet have been studied by Rollier (481), Hausser and Vahle (482), Tisdall and Brown (483), Sonne (484), and others.

Ultra-violet radiation may be regarded as extending between, say, 2,700 and 3,350 angstrom units wavelength, i.e. between 0·27 and 0·335 micron. Below, say, 3,000 angstrom unit, or 0·3 micron, radiation is eliminated even by clear air. Since individual smoke particles are about 0·5 micron diameter, they will not scatter, but reflect and refract the ultra-violet radiation, so that the recognized serious depletion of ultra-violet by the impurities of the atmosphere is probably due to dust particles of less than 0·5 micron diameter, and even 0·335 micron diameter, which will scatter all radiation of wavelength between 0·335 and 0·300 micron. It seems, therefore, probable that ultra-violet radiation which is scattered and lost to the great detriment of humanity, is not primarily due to smoke, but to the teeming still-finer dust content of normal air. This emphasizes the important need of studying dusts as distinct from smokes. At the same time, the reservation must be made of the possible atmospheric existence of some smoke particles of the order 0·335 micron diameter, since Whytlaw-Gray and Patterson (205) show that some laboratory smokes are of this order, e.g. mercury 0·3 micron, and mercuric chloride 0·36 micron—if the observed density be regarded as the effective one.

Various means have been devised for measuring natural ultra-violet deficiency due to atmospheric impurity. Thus

Ashworth (485) employed the photographic plate ; Anderson and Robinson (486), oxalic acid ; Clark (487), zinc sulphide ; and Hill and Eidinow (488), methylene blue. Meller, Hibben and Warga (197*g*) compared their Rentschler ultra-violet meter method (*cf.* the Scientific Study of Dusts) with the others, and found that the various methods are not sensitive to exactly the same spectral region, nor equally sensitive to the same wavelengths.

Some of the preliminary results of Meller and Warga (197*h*) are given below. These indicate the price which dust and smoke demand in the currency of the beneficient ultra-violet ray, as also the chart results illustrated in Fig. 4, p. 229.

TABLE IX

		Clear Days. Light Smoke Blanket.				Cloudy Days. Light Smoke Blanket.			
	Month.	*Days without.*		*Days with.*		*Days without.*		*Days with.*	
1931.	July.	5	70,465	0	—	5	52,035	0	—
	Aug.	2	69,880	0	—	6	30,075	0	—
	Sept.	2	50,225	2	35,745	3	36,270	0	—
	Oct.	3	40,915	4	27,270	7	25,450	2	22,890
	Nov.	2	31,025	2	23,790	9	13,550	5	8,520
	Dec.	2	23,980	1	18,920	3	9,300	13	5,315
1932.	Jan.	1	27,245	1	20,070	2	14,510	12	3,820
	Feb.	2	45,660	2	17,775	2	24,300	10	15,585
	Mar.	0	—	0	—	9	28,280	8	12,150
	Apr.	4	73,730	0	—	7	59,180	6	23,290
	May	6	85,730	0	—	5	49,490	0	—
	June	2	76,000	0	—	5	60,225	3	31,050

N.B.—These figures are for Pittsburgh, Pennsylvania, and the averages; e.g. 70,465, give the number of Rentschler ultra-violet units per hour.

Although the results (only partially reproduced) are specifically referred to by the authors as but preliminary, they show in a definite manner (*a*) the variation of ultra-violet radiation with the season of the year, and (*b*) the reduction therein due to light smoke blankets. The full table shows the reduction due to partly as well as fully cloudy conditions.

The table indicates either that (1) the " light smoke blanket " contains a large number of particles less than 0·5 micron diameter, or, if 0·5 micron diameter be accepted as the lower limit of smoke particle size, (2) it is in all probability really a dust blanket that is stopping the ultra-violet radiation. For the question of the arbitrariness of the distinction between " smoke " and " dust " particles in the atmosphere is involved. In order to establish a real, scientific basis of distinction, it

seems necessary to refer to definite characteristics which distinguish " smoke " from " dust " particles. This is provided by the generality that smoke particles in smoke systems are constantly growing larger by agglomeration, whereas dust particles in dust systems are—on the other hand—almost certainly constantly growing smaller by disintegration. Such particles, which were originally smoke particles, and are dispersed in the atmosphere, will almost certainly have ceased to be smoke, and have become dust particles under this differentiation, at any time when their ultra-violet absorption is being studied. It is difficult, therefore, to avoid the conclusion that the " smoke " nuisance is really a portion of the great dust nuisance, and that, by studying the former exclusively, the major portion, viz. 60%, of the one large central problem is being ignored. " Smoke " has become dust before it is dispersed in the atmosphere, in fact as soon as the increasing-size tendency of the original smoke system was destroyed.

For these reasons, and because it is impracticable to determine in what proportion the different size zones are augmented by ever-fresh, ever-forming, additional systems—" smoke " or " dust "—the atmospheric pollution problem merges, as regards the individuality of its units into the vast, world-wide, system—probably co-extensive with the atmosphere—of the staubosphere.

Increasing interest in dust disease is shown by (*a*) the recent symposium (543) when F. S. Fowweather advanced evidence that nature—not amount—of silica was a determining function; W. R. Jones maintained that silicate minerals such as sericite and asbestos—a large number of sericite fibres underlying ganister near Sheffield—were chief disease causes, and advanced a new oil-contamination-free method for supplying air to workers; F. V. Tideswell described a method for readily-lung-soluble silica estimation; and other workers contributed to the discussion. Also (*b*) by the actuarial interest witnessed by the insurance booklet " Silicosis " (544) outlining dust determination methods, prevention measures, etc., and giving a valuable list of industries and processes using silica, due to R. B. Ladoo (545).

Thus, the personal incidence of dust—whether in preventing ultra-violet benefit, or introducing disease positively by the lung—is again ranking as a most important aspect, just as original human interest in dust was due to this personal incidence.

GLOSSARY

1 kilometre = 1 km. = 1,000 metres = 39,370 inches = five-eighths mile.

1 metre = 100 centimetres (cm.) = 39·37 inches (in.).

1 centimetre = two-fifths inch.

1 millimetre = one-tenth centimetre = one twenty-fifth inch.

1 micron = u = one thousandth millimetre (mm.) = 10^{-3} mm. = 10^{-4} cm.

1 millimicron = uu = one thousandth micron (u) = one millionth millimetre = 10^{-6} mm. = 10^{-7} cm.

1 angstrom unit (A.U.) = one-tenth uu = one ten-thousandth micron (u) = one ten-millionth millimetre = 10^{-7} mm. = 10^{-8} cm. = 10^{-10} m. = 1 " tenth-metre."

$10^1 = (10 \times 1) = 10$;

$$2 \cdot 5 \times 10^1 = 2 \cdot 5\ (10 \times 1) = 2 \cdot 5 \times 10 = 25$$

$10^2 = (10 \times 10) = 100$;

$$3 \cdot 8 \times 10^2 = 3 \cdot 8\ (10 \times 10) = 3 \cdot 8 \times 100 = 380$$

$10^3 = (10 \times 10 \times 10) = 1{,}000$;

$$4 \cdot 6 \times 10^3 = 4 \cdot 6\ (10 \times 10 \times 10) = 4 \cdot 6 \times 1{,}000 = 4{,}600$$

$10^4 = (10 \times 10 \times 10 \times 10) = 10{,}000$;

$$9 \cdot 3 \times 10^4 = 9 \cdot 3\ (10 \times 10 \times 10 \times 10) = 9 \cdot 3 \times 10{,}000 = 93{,}000$$

and so forth, for index 5, adding five 0's to 1, i.e. 100,000
for index 6, adding six 0's to 1, i.e. 1,000,000

$10^{-1} = \frac{1}{10} =$ one-tenth;

$$3 \cdot 3 \times 10^{-1} = 3 \cdot 3 \left(\frac{1}{10}\right) = \frac{3 \cdot 3}{10} = \text{one third.}$$

$10^{-2} = \frac{1}{100}$ = one-hundredth;

$$2 \cdot 5 \times 10^{-2} = 2 \cdot 5 \left(\frac{1}{100}\right) = \frac{2 \cdot 5}{100} = \text{one-fortieth.}$$

$10^{-3} = \frac{1}{1{,}000}$ = one-thousandth;

$$3 \cdot 3 \times 10^{-3} = 3 \cdot 3 \left(\frac{1}{1{,}000}\right) = \frac{3 \cdot 3}{1{,}000} = \text{one three-hundredth.}$$

$10^{-4} = \frac{1}{10{,}000}$ = one ten-thousandth;

$$2 \cdot 5 \times 10^{-4} = 2 \cdot 5 \left(\frac{1}{10{,}000}\right) = \frac{2 \cdot 5}{10{,}000} = \text{one four-thousandth.}$$

and so forth, for index 5, adding five 0's to 1
(as denominator), i.e. $\frac{1}{100{,}000}$ = one hundred-thousandth.

for index 6, adding six 0's to 1
(as denominator), i.e. $\frac{1}{1{,}000{,}000}$ = one millionth.

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1 kilometre (km.) = one thousand (10^3) metres (m.) = one hundred thousand (10^5) centimetres (cm.) = one million (10^6) millimetres (mm.).

1 millimetre (mm.) = one-tenth (10^{-1}) centimetres (cm.) = one thousandth (10^{-3}) metre (m.) = one millionth (10^{-6}) kilometre (km.).

1 litre (l.) = 35·2 fluid ounces = 1·76 pints = 1,000 cubic centimetres (c.c.).

1 cubic centimetre (c.c.) volume weighs 1 gram (gm.) weight, when density is 1.

1 kilogram (kgm.) = 35·2 ounces av. = 2·2 pounds av. = 1,000 grams (gm.).

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